Charmless Two Body b Decays from CDF

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For the CDF collaboration

Fermilab W&C 8/6/2004

Outline

- A bit of history
  - Hadronic b trigger (SVT)
- Motivation
- Method
- Results
- Prospects
- Summary

A $B^0 \to \pi^+\pi^-$ TRIGGER FOR CDF

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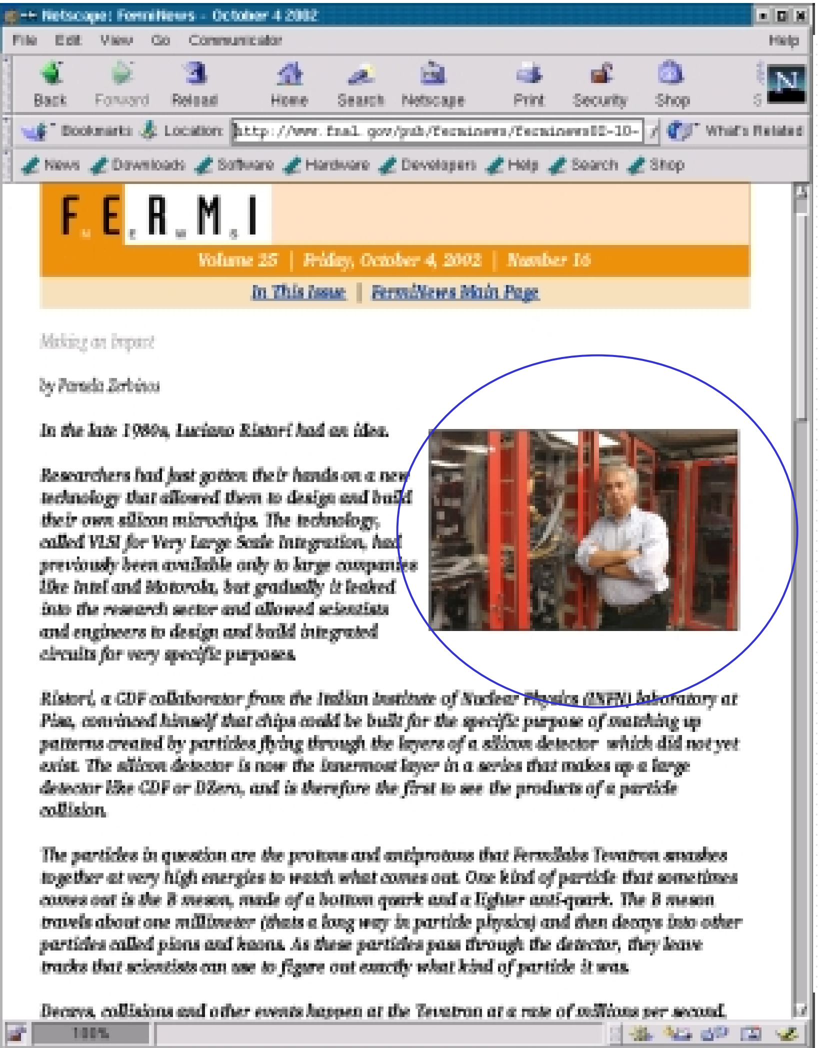
SUMMARY REPORT OF THE WORKING GROUP ON MEASUREMENT OF ANGLE ALPHA WORKSHOP ON B PHYSICS AT HADRON COLLIDERS, SNOWMASS, JUNE 1993

1. INTRODUCTION

We have studied how to implement in CDF a trigger for the process $B^0 \to \pi^+\pi^-$, exploiting the new trigger hardware being built for Run II ~~(1996/1997)~~. (2001-200?)

The trigger we propose is based on online measurement of impact parameters, a very important handle for a decay channel that is otherwise almost featureless. The new devices that will make this trigger possible are, at Level 1, the new fast tracker for the Central Drift Chamber (XFT[1]) and, at Level 2, the Silicon Vertex Tracker (SVT[2]), allowing online tracking in the new Silicon Vertex detector (SVX II[3]). We evaluate rates and efficiency of the proposed trigger, and discuss its feasibility.

From design to reality



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Making an Impact

by Pamela Zerbinos

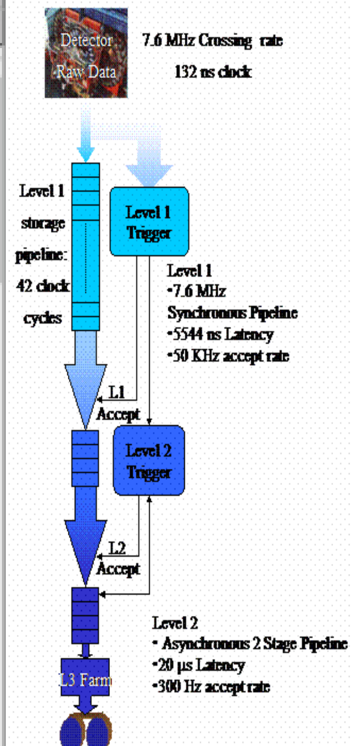
In the late 1980s, Luciano Ristori had an idea.

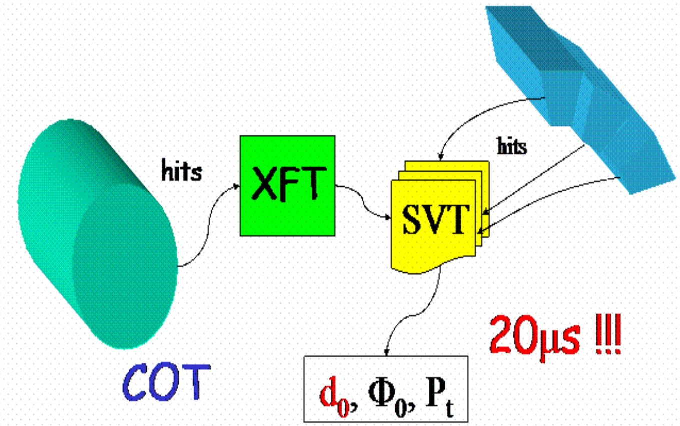
Researchers had just gotten their hands on a new technology that allowed them to design and build their own silicon microchips. The technology, called VLSI for Very Large Scale Integration, had previously been available only to large companies like Intel and Motorola, but gradually it leaked into the research sector and allowed scientists and engineers to design and build integrated circuits for very specific purposes.

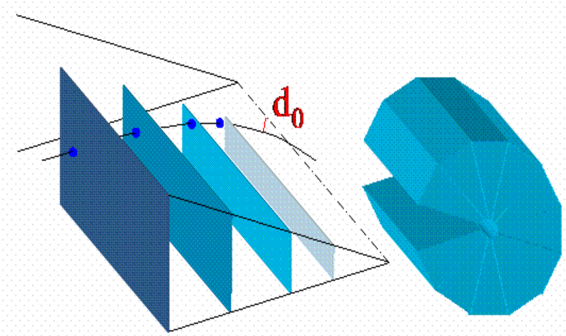
Ristori, a CDF collaborator from the Italian Institute of Nuclear Physics (INFN) laboratory at Pisa, convinced himself that chips could be built for the specific purpose of matching up patterns created by particles flying through the layers of a silicon detector which did not yet exist. The silicon detector is now the innermost layer in a series that makes up a large detector like CDF or DZero, and is therefore the first to see the products of a particle collision.

The particles in question are the protons and antiprotons that Fermilab's Tevatron smashes together at very high energies to watch what comes out. One kind of particle that sometimes comes out is the B meson, made of a bottom quark and a lighter anti-quark. The B meson travels about one millimeter (that's a long way in particle physics) and then decays into other particles called pions and kaons. As these particles pass through the detector, they leave tracks that scientists can use to figure out exactly what kind of particle it was.

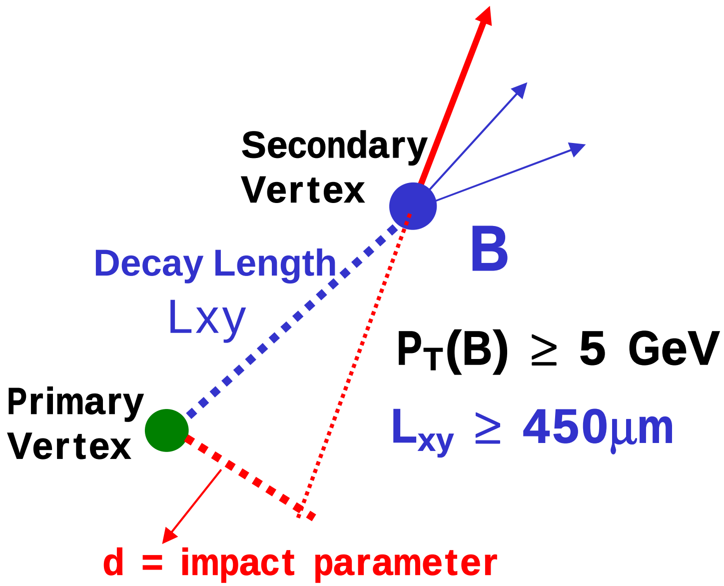
Decays, collisions and other events happen at the Tevatron at a rate of millions per second.

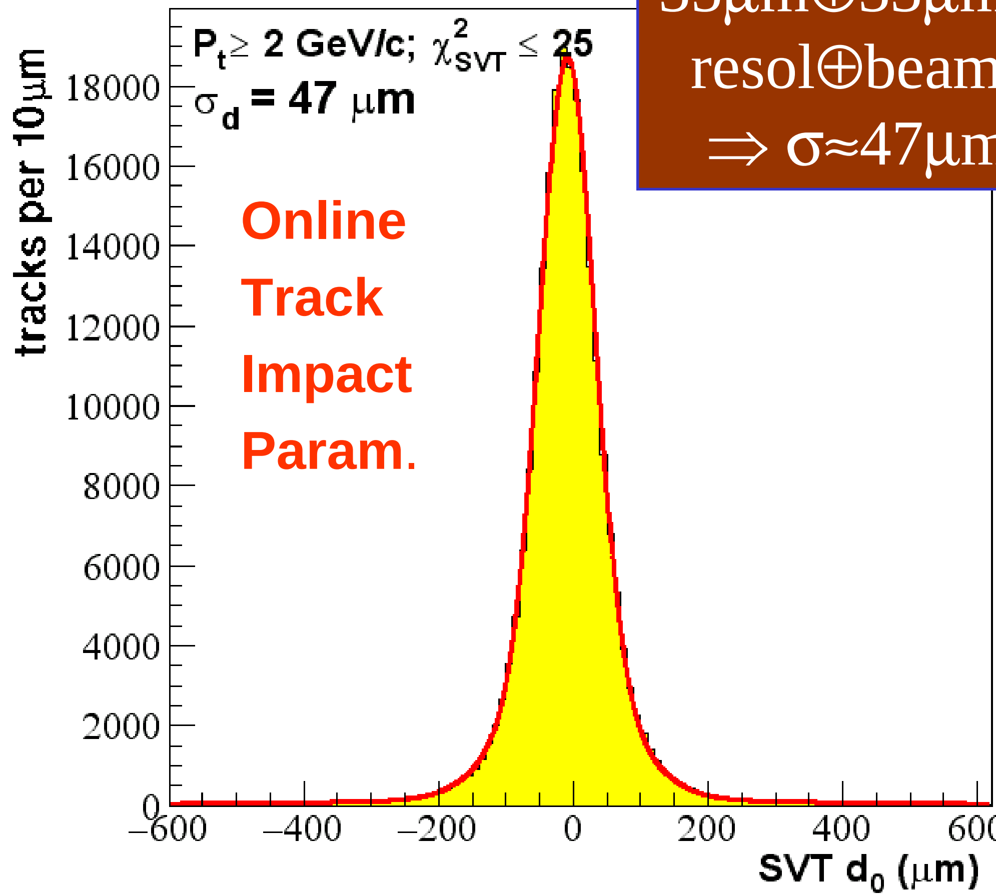






Silicon Vertex Tracker

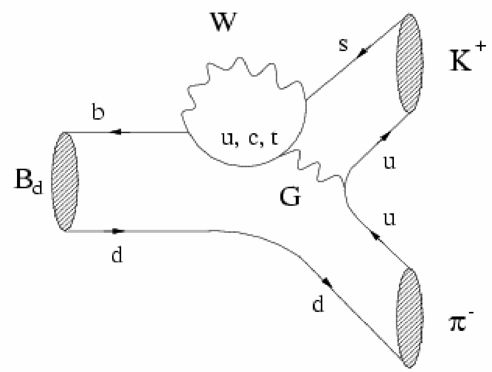


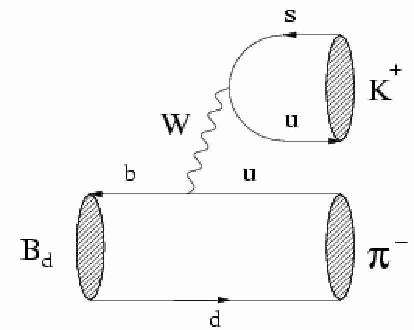


$35\mu m \oplus 33\mu m$
resol$\oplus$beam
$\Rightarrow \sigma \approx 47\mu m$

Motivations

$B_d \rightarrow K\pi$ vs $B_d \rightarrow \pi\pi$





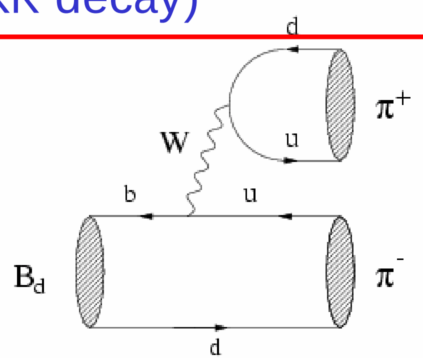
Original observation of Cleo:

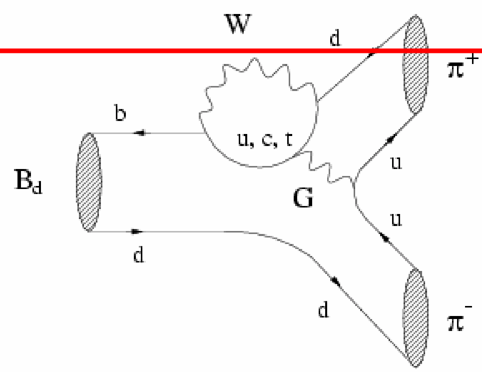
BR($K\pi$)~=4BR($\pi\pi$)

made it clear that penguins are an important element in two body B decays.

Tree is Cabibbo-suppressed →Penguin dominant in Bd→$K^+\pi^-$ decays

(Similar conclusion apply to its SU(3) partner Bs→KK decay)





Revised strategies to extract CKM matrix elements:

- use several Isospin related decays modes
- Measure B_s and B_d SU(3) related modes (hadron colliders !)

Why B→hh' at CDF (1)

- Penguin-tree interference provide information on angle γ
  - A measure of the relative penguin to tree contribution needed
  - Use of both $B_s \to hh'$ processes and $B_d \to hh'$, relies on flavour SU(3) symmetry and provides a theoretically clean method
  - CDF is the first experiment to be sensitive to $B_s \to hh$ decays
  - Measure BR($B_s \to K^+K^-$) relative to BR($B_d \to K^+\pi^-$)

- Significant direct CP violation observed in B decay in the channel $B_d \to K^+\pi^-$ (BABAR hep-ex/0407057) !
  - CDF measurement of $A_{CP}(B_d \to K^+\pi^-)$ consistent with Babar & Belle.
  - Will eventually be competitive with B-factories with more data
  - CDF will eventually observe $Bs \to K^-\pi^+$ and measure CP asymmetry for this mode also
  - Direct CP asymmetry fix theory parameters and allow more precise predictions for yet to be observed observables

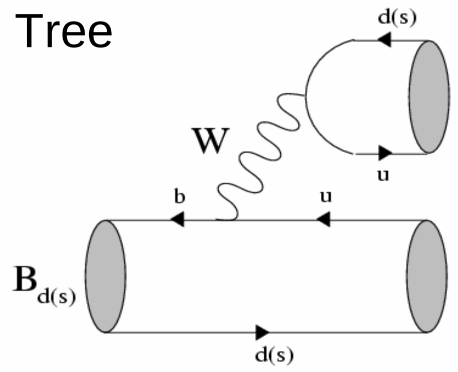
Why B→hh' at CDF (2)

- Measurement of the time evolution of the untagged $B_s \to K^+K^-$ sample sensitive to $\Delta\Gamma_s$!
- If $\Delta\Gamma_s$ in $B_s \to K^+K^-$ turns out different from the time evolution of the CP even component in $B_s \to J/\psi\phi$ he may have hint for New Physics

- CDF is searching for charmless two body Λ_b decays where large CP violation is predicted by theory

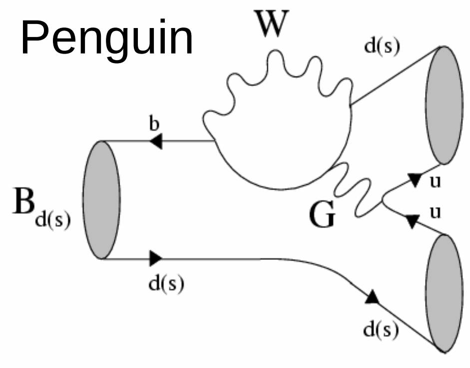
$B_{d(s)} \rightarrow hh'$ penguin and tree

Tree



Amplitude ~ T

Penguin



Amplitude ~ P

$$A(B_d \rightarrow \pi^+\pi^-) = C\left[e^{i\gamma} - de^{i\vartheta}\right]$$

$$A(B_s \rightarrow K^+K^-) = \left(\frac{\lambda}{1-\lambda^2/2}\right)C'\left[e^{i\gamma} + \left(\frac{1-\lambda^2}{\lambda^2}\right)d'e^{i\vartheta'}\right]$$

Glossary

C, C' : CP conserving strong amplitudes

d, d' : "penguin to tree ratio"

θ, θ' : strong phase difference between penguin and tree

Amplitudes related by U-spin symmetry of strong interactions (s↔d interchange) !

$$d = d'; \ \vartheta = \vartheta'$$

B→hh observables

$$A_{cp}(t) = A_{cp}^{dir} \times \cos\Delta m t + A_{cp}^{mix} \times \sin\Delta m t$$

$$A_{cp}^{dir}(\pi^+\pi^-) = -\frac{2d\sin\theta\sin\gamma}{1-2d\cos\theta\cos\gamma+d^2}$$

$$A_{cp}^{dir}(K^+K^-) = \frac{2d\frac{1-\lambda^2}{\lambda^2}\sin\theta\sin\gamma}{1+2d\frac{1-\lambda^2}{\lambda^2}\cos\theta\cos\gamma+(\frac{1-\lambda^2}{\lambda^2})^2 d^2}$$

$$A_{cp}^{mix}(K^+K^-) = \frac{\sin 2\gamma+2d\frac{1-\lambda^2}{\lambda^2}\cos\theta\sin\gamma}{1+2d\frac{1-\lambda^2}{\lambda^2}\cos\theta\cos\gamma+d^2(\frac{1-\lambda^2}{\lambda^2})^2}$$

$$A_{cp}^{mix}(\pi^+\pi^-) = \frac{\sin 2(\beta+\gamma)-2d\cos\theta\sin(2\beta+\gamma)+d^2\sin 2\beta}{1-2d\cos\theta\cos\gamma+d^2}$$

$$A_{cp}^{mix}(J/\psi K_s) = \sin 2\beta$$

Many related observables determine the angle γ using $B_s \to KK/B_d \to \pi\pi$ CDF data alone

Time dependent CP asymmetry requires b-flavor tagging and need more statistics

(a major goal for CDF Run II)

Branching Ratio measurements can constrain theory too!

R.Fleisher hep-ph/0405091;

D.London, J.Matias hep-ph/0404009

$$H = \left(\frac{1-\lambda^2}{\lambda^2}\right)\left(\frac{f_K}{f_\pi}\right)^2\left[\frac{BR(B_d \to \pi^+\pi^-)}{BR(B_d \to K^\pm\pi^\mp)}\right] = \frac{1-2d\cos\vartheta\cos\gamma+d^2}{\left(\frac{\lambda^2}{1-\lambda^2}\right)^2+2\left(\frac{\lambda^2}{1-\lambda^2}\right)d\cos\vartheta\cos\gamma+d^2}$$

$$R_d^s = \left[\frac{BR(B_s \to K^+K^-)}{BR(B_d \to \pi^+\pi^-)}\right] = \left(\frac{1-\lambda^2}{\lambda^2}\right)\left|\frac{C'}{C}\right|^2 \frac{\left(\frac{\lambda^2}{1-\lambda^2}\right)^2+2\left(\frac{\lambda^2}{1-\lambda^2}\right)d\cos\vartheta\cos\gamma+d^2}{1-2d\cos\vartheta\cos\gamma+d^2} F_{ps}$$

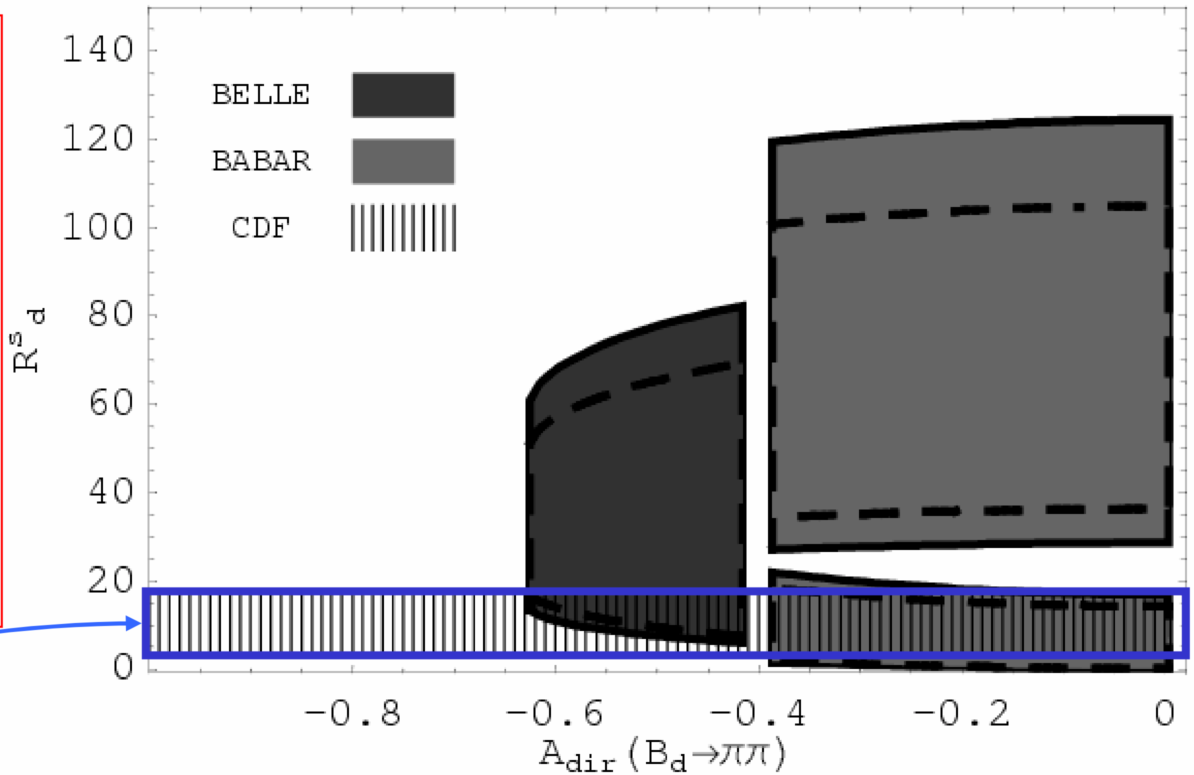
Phase space factor = 0.92

QCD sum rules: 1.76+0.15-0.17 (A.Khodyamirian et al., Phys.Rev D68 114007)

$B_s \rightarrow KK$ vs $B_d \rightarrow \pi\pi$

Inputs:

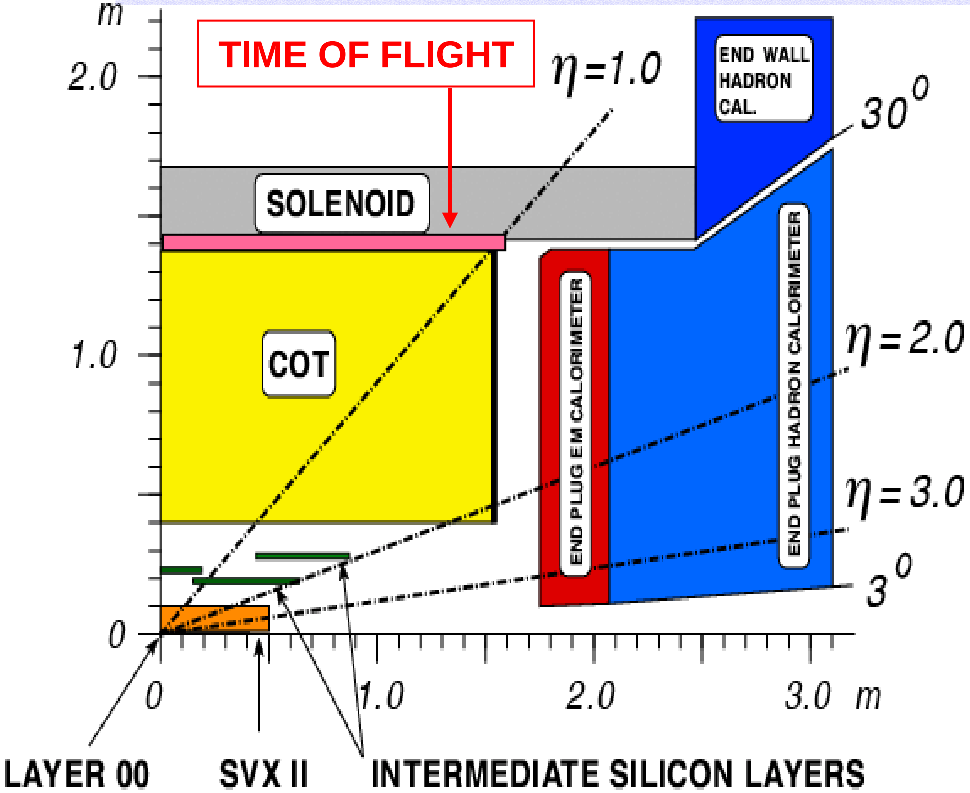
- $2\beta = 47^o$ $\gamma = 65^o \pm 7^o$
- Current Babar/Belle measurement
- $\pm 20\%$ SU(3) breaking effect as additional theory error



D.London, J.Matias
hep-ph/0404009

- Determine allowed region in the R vs $A_{CP}^{dir}(\pi\pi)$ plan from Babar & Belle measurements
- Check Theory (or claim New Physics…) by comparing the allowed range with CDF experiment data (Lepton Photon 03 prel. result)

Quadrant of CDF II Tracker



TOF: 100ps resolution, 2 sigma K/π separation for tracks below 1.6 GeV/c (significant improvement of B_s flavor tag effectiveness)

COT: large radius (1.4 m) Drift C.

- 96 layers, 200ns drift time
- Precise P_T above 400 MeV/c
- Precise 3D tracking in $|\eta|<1$

$\sigma(1/P_T) \sim 0.1\%\mathrm{GeV}^{-1}$; $\sigma(\mathrm{hit}) \sim 150\mu\mathrm{m}$

- dE/dx info provides >1.3 sigma K/π separation above 2 GeV

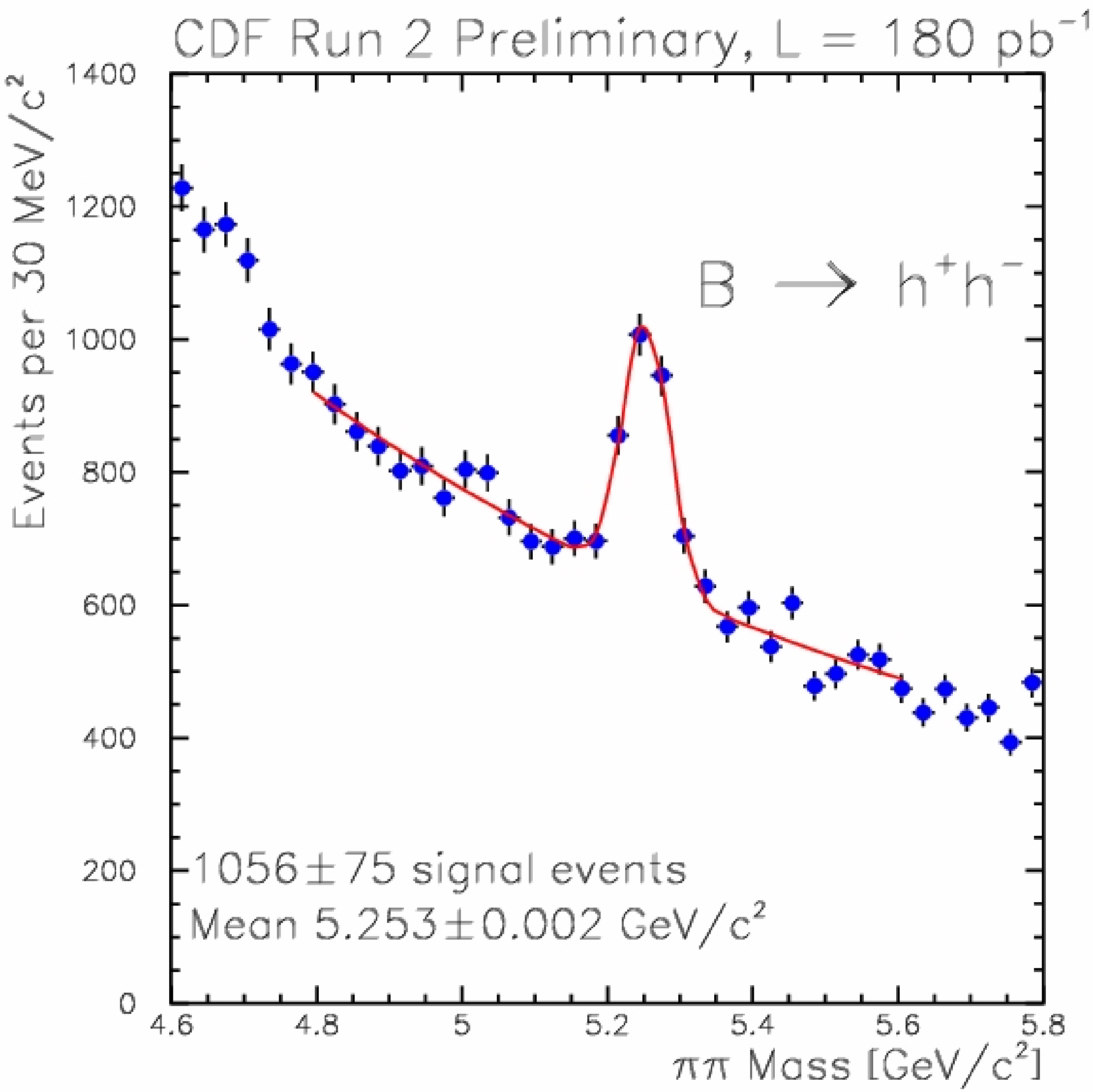
SVX-II + ISL: 6 (7) layers of double-side silicon (3cm < R < 30cm)

- Standalone 3D tracking up to $|\eta|= 2$
- Very good I.P. resolution: ~30μm (~20 μm with Layer00)

LAYER 00: 1 layer of radiation-hard silicon at very small radius (1.5 cm) (expected 50 fs proper time resolution in $B_s \to D_s \pi$)

Measurement of the relative fractions and CP asymmetry in $B^0_{d,s} \to h^+h'^-$

$B^0 \rightarrow h^+h'^-$ mass plot – trigger like selection

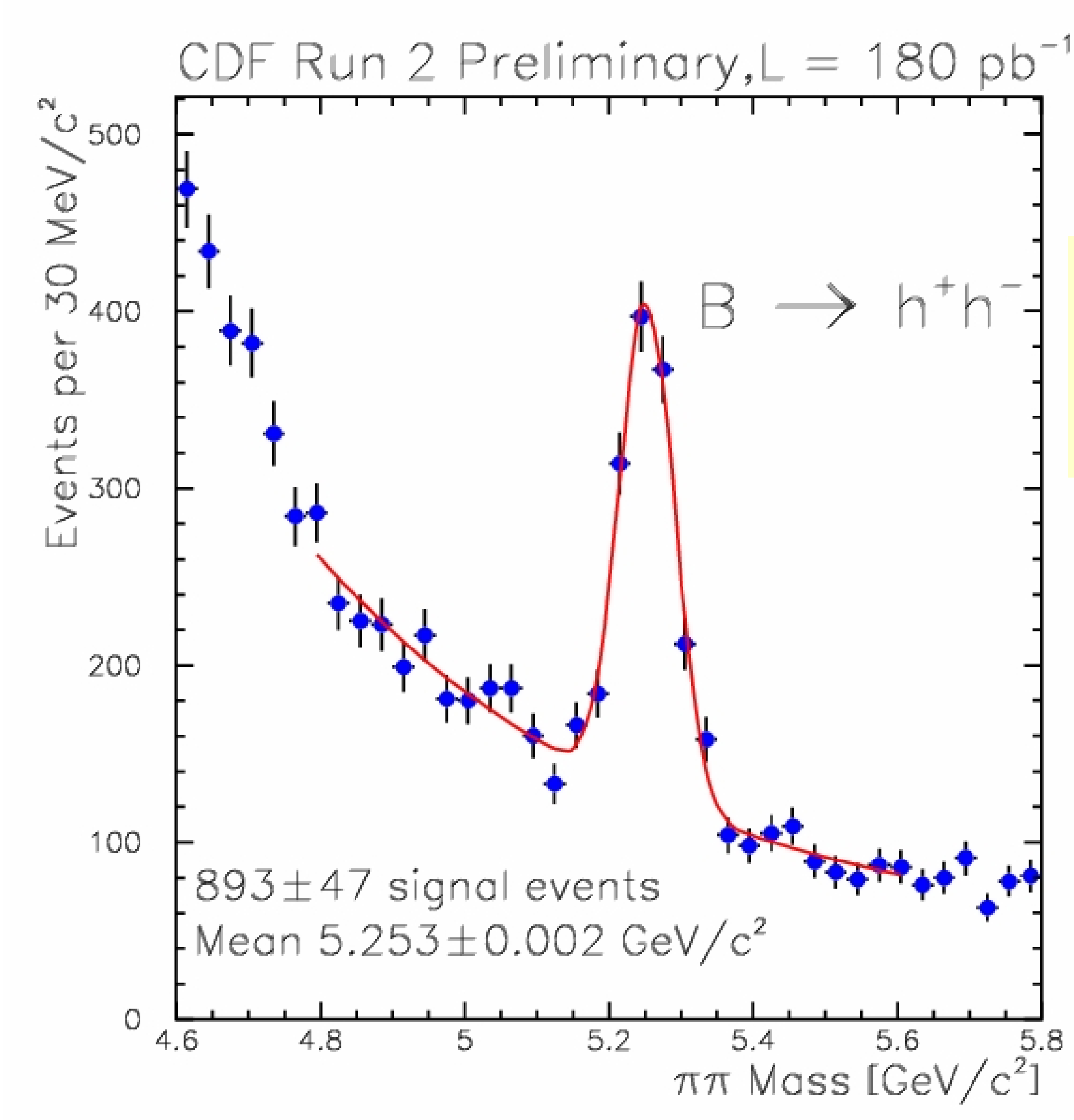


Selection optimized using sideband data and MC

Parameter	value
# axial COT hits	≥ 20
# stereo COT hits	≥ 20
# axial SVXII hits	≥ 3
$\max(\|\eta(\pi_1)\|, \|\eta(\pi_2)\|)$	≤ 1
$\min(p_T(\pi_1), p_T(\pi_2))$	≥ 2 GeV/c
$p_T(\pi_1) + p_T(\pi_2)$	≥ 5.5 GeV/c
$q(\pi_1) \cdot q(\pi_2)$	< 0
$\Delta\phi(\pi_1, \pi_2)$	$[20°, 135°]$
$\min(\|d_0(\pi_1)\|, \|d_0(\pi_2)\|)$	≥ 0.0150 cm
$\max(\|d_0(\pi_1)\|, \|d_0(\pi_2)\|)$	≤ 0.1000 cm
$d_0(\pi_1) \cdot d_0(\pi_2)$	< 0
$\|\eta(B)\|$	≤ 1
$\|d_0(B)\|$	≤ 0.0080 cm
$L_{xy}(B)$	≥ 0.0300 cm
~~B isolation~~	~~≥ 0.5~~

Online trigger cuts are just a little looser!!!

$B^0 \rightarrow h^+h'^-$ mass plot – isolation cut added



Define B isolation as :

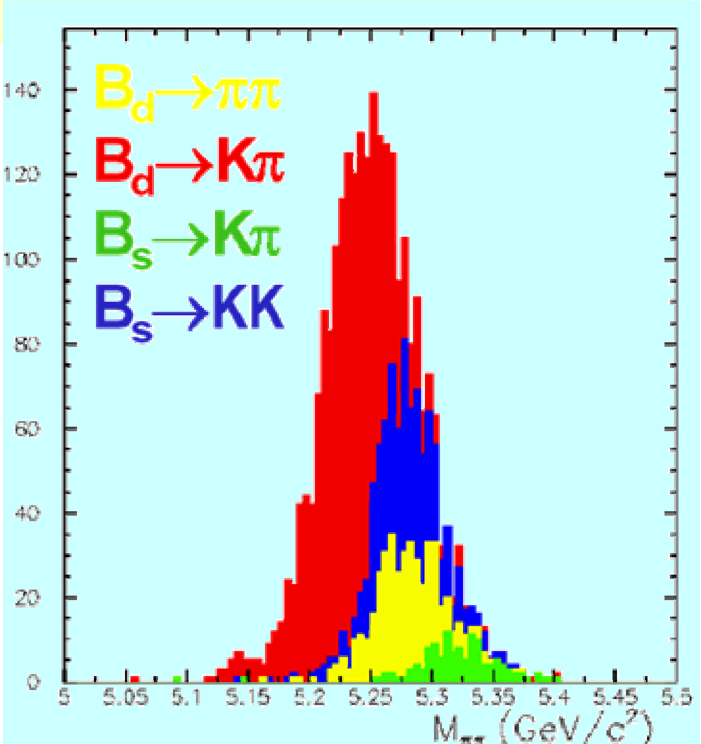
$$Isol = \frac{P_T(B)}{P_T(B) + \sum_i P_T^i}$$

Where the sum over all charged tracks within a cone of radius R=1 around candidate B meson direction

Strategy

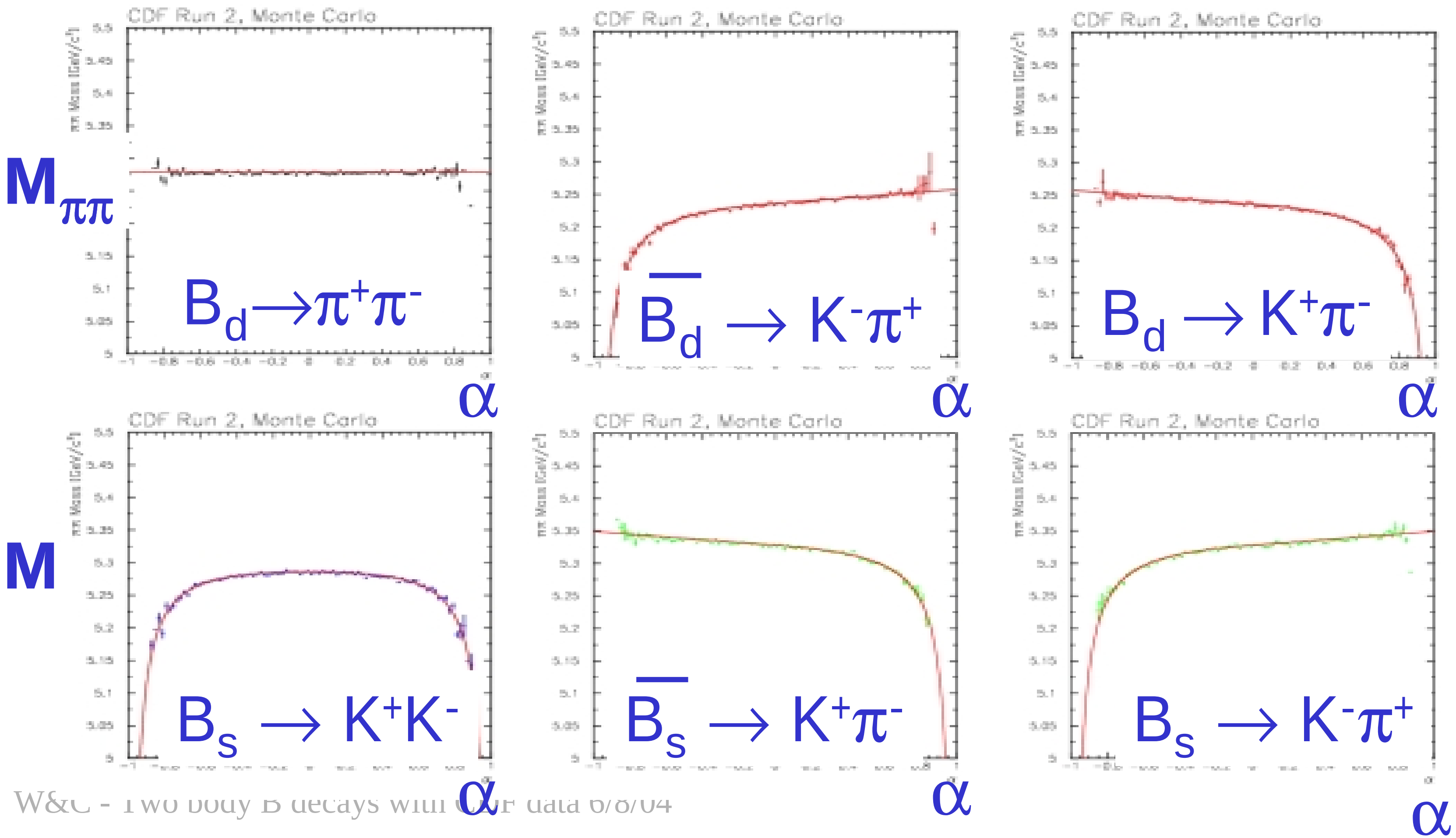
To measure Branching Franction and CP asymmetry we need to separate the 4 signals superimposed in the mass peak. Fit the composition of the $B^0 \rightarrow h^+h'^-$ signal with a likelihood that combines the invariant mass ($M_{\pi\pi}$) ,the kinematics and PID information (dE/dx from drift chamber).

Notice how the $B_s \rightarrow KK$ and $B_d \rightarrow \pi\pi$ sit one on top of the other. dE/dx separation crucial for separate the two.

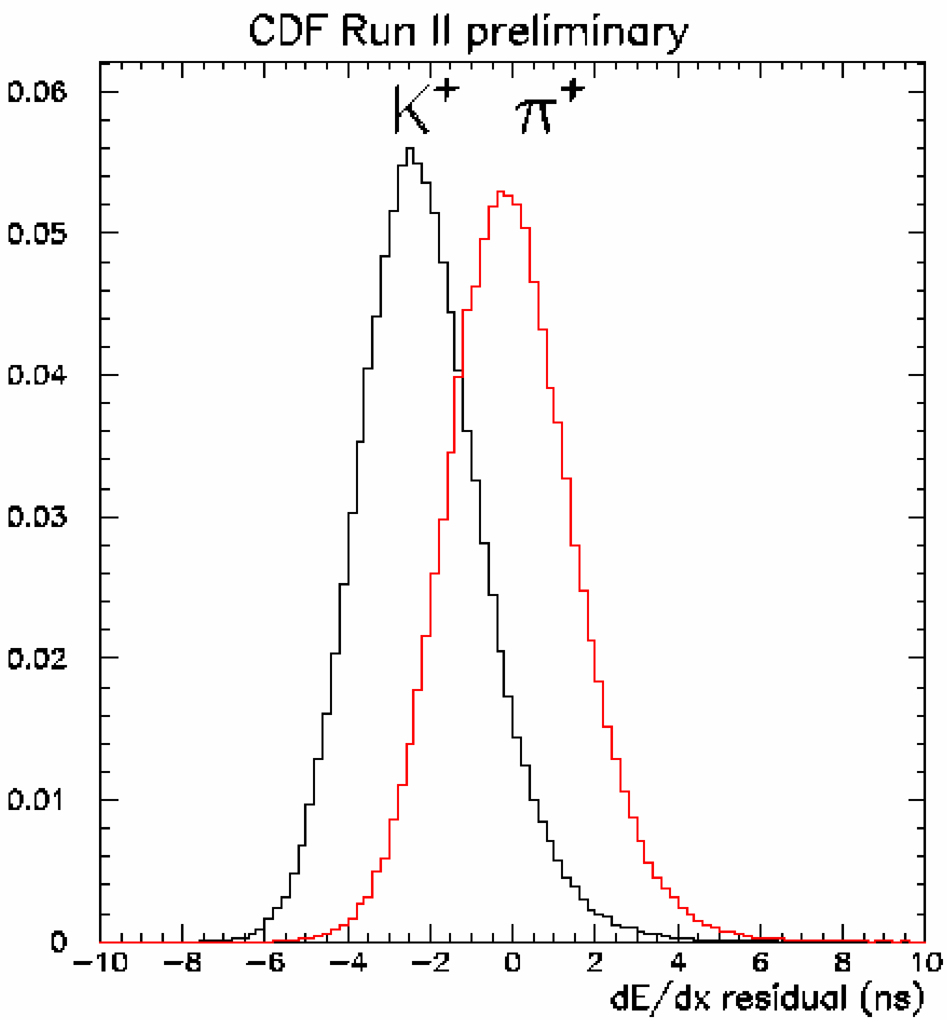


Handle 1: kinematics

Invariant mass ($\pi\pi$ hypothesis) vs signed momentum imbalance α**=[1–p1/p2] x q1,** discriminates among the four signals and the B flavour for flavour specif decays.



Handle 2: PID from dE/dx



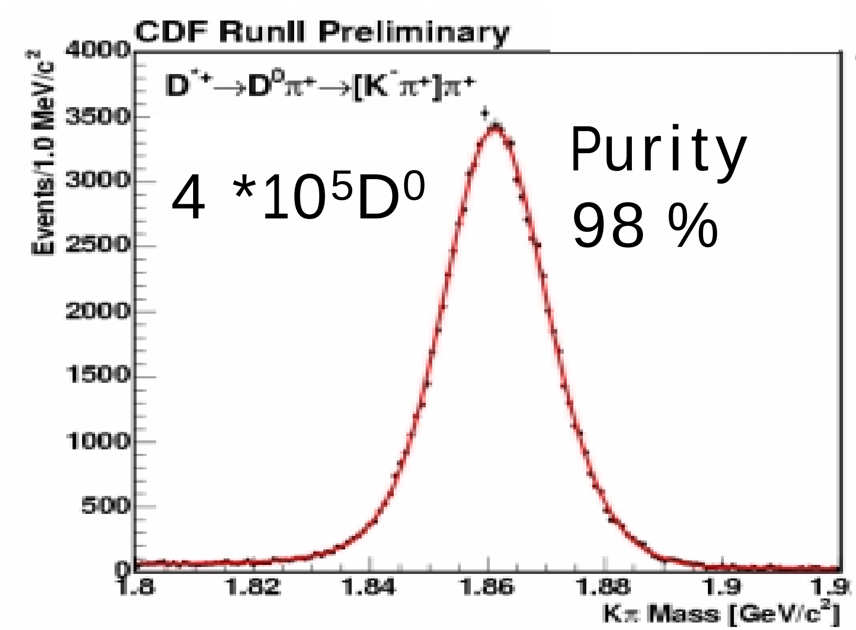
1.39 σ π/K separation

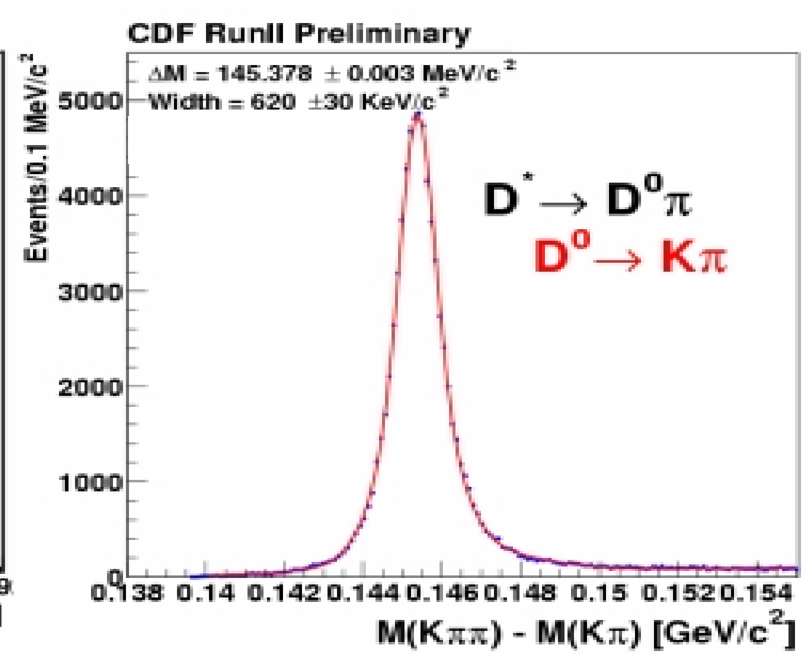
For P>2 GeV/c

Note:

The combined fit with PID at his level provides an effective separation only 40% worse than a perfect PID would do...

Handle 2 (aside): huge calibration sample from $D^{*\pm} \rightarrow \overset{(-)}{D}{}^0 \pi^\pm$ decays !





- CDF is accumulating huge sample of clean D signals with the SVT
- Crucial point for accurate calibration and understanding of the dE/dx measurement
- Crucial for understanding trigger efficiencies and its dependence on particle type

World best BR and CP asymmetry in $D^0 \rightarrow K^+K^-$ and $\pi^+\pi^-$ final state from CDF submitted for publication today!

The Likelihood

Fit the events falling in the range:

$(4.85 < M_{\pi\pi} < 5.8)$ U ($-0.8 < \alpha < 0.8$) U (all dE/dx)

$$\mathcal{L} = \prod_{i=1}^{Nevents} \mathcal{L}_i$$

$$\mathcal{L}_i = b \cdot \mathcal{L}^{bckg} + (1-b) \cdot \mathcal{L}^{sign}$$

Signal Likel.

Background Likelihood

Background fraction (float)

The Likelihood (cont'd)

$$\mathcal{L}^{sig} = \sum_j f_j \cdot \mathcal{L}_j^{kin} \cdot \mathcal{L}_j^{PID}$$

Signal likelihood

dE/dx term

kinematics term

fraction of events of the jth mode

Fit the fraction f_j of each of the 6 modes:

$B_d \to \pi^+ \pi^-$ $B_d \to K^+ \pi^-$ $\overline{B}_d \to K^- \pi^+$

$B_s \to K^+ K^-$ $B_s \to K^- \pi^+$ $\overline{B}_s \to K^+ \pi^-$

With normalization condition $f_6 = 1 - \sum_{j=1}^{5} f_j.$

$$\mathcal{L}^{bckg} = \mathcal{L}_{bckg}^{kin} \cdot \mathcal{L}_{bckg}^{PID}$$

Background likelihood

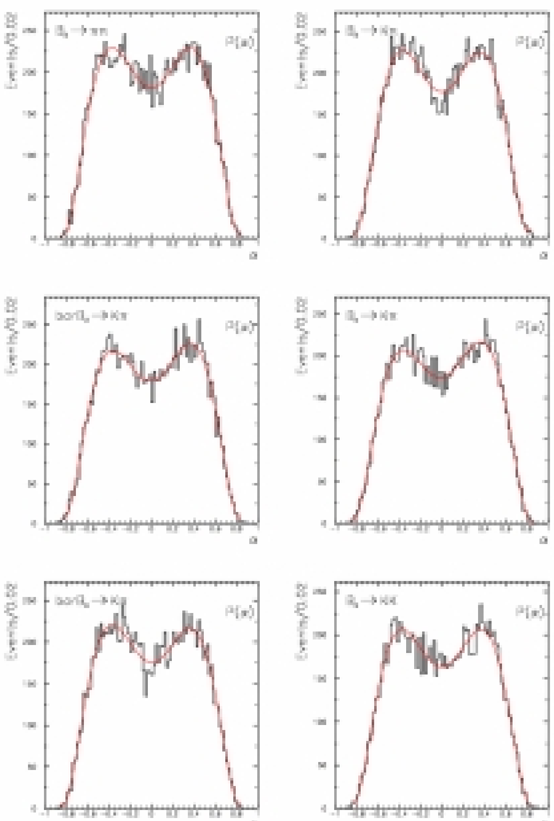
The kinematics term (signal)

$$\mathcal{L}_j^{kin} = pdf_j^{kin}(M_{\pi\pi}, \alpha\ ;\ \sigma, \mathcal{M}(\alpha)) = P(\alpha) \cdot \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{M_{\pi\pi} - \mathcal{M}(\alpha)}{\sigma}\right)^2}$$

Pdf of α variable.
Template from MC

Invariant mass width assuming tracks in each mode assigned with correct masses

Expected value of the $\pi\pi$ invariant mass (function of α).
Input the fit with its analytic expression



mode	$\mathcal{M}^2(\alpha) = \mathcal{M}^2(\alpha < 0)$
$B_d \to \pi^+\pi^-$	$M^2_{B^0_d}$
$B^0_d \to \pi^- K^+$	$M^2_{B^0_d} + (2+\alpha)(m^2_\pi - m^2_K)$
$\overline{B}^0_d \to K^-\pi^+$	$M^2_{B^0_d} + (1+\frac{1}{1+\alpha})(m^2_\pi - m^2_K)$
$\overline{B}^0_s \to \pi^- K^+$	$M^2_{B^0_s} + (2+\alpha)(m^2_\pi - m^2_K)$
$B^0_s \to K^-\pi^+$	$M^2_{B^0_s} + (1+\frac{1}{1+\alpha})(m^2_\pi - m^2_K)$
$B_s \to K^+K^-$	$M^2_{B^0_s} + (3+\alpha+\frac{1}{1+\alpha})(m^2_\pi - m^2_K)$

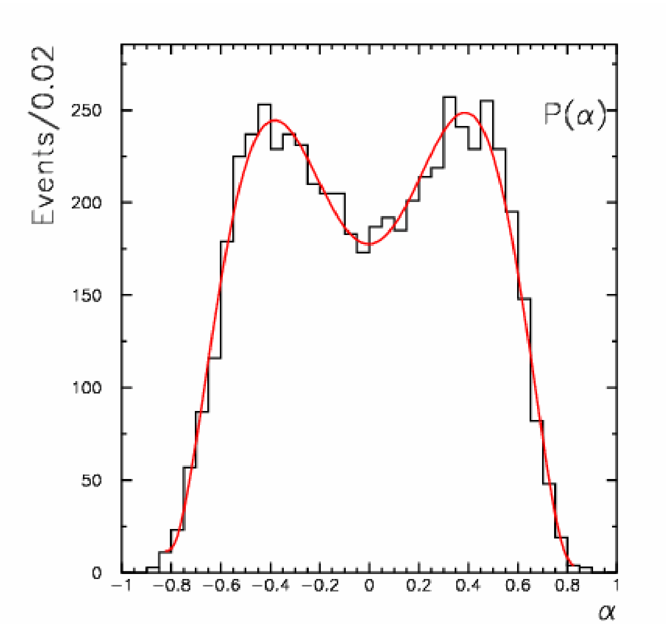
mode	$\mathcal{M}^2(\alpha) = \mathcal{M}^2(\alpha > 0)$
$B_d \to \pi^+\pi^-$	$M^2_{B^0_d}$
$\overline{B}^0_d \to \pi^+ K^-$	$M^2_{B^0_d} + (2-\alpha)(m^2_\pi - m^2_K)$
$B^0_d \to K^+\pi^-$	$M^2_{B^0_d} + (1+\frac{1}{1-\alpha})(m^2_\pi - m^2_K)$
$B^0_s \to \pi^+ K^-$	$M^2_{B^0_s} + (2-\alpha)(m^2_\pi - m^2_K)$
$\overline{B}^0_s \to K^+\pi^-$	$M^2_{B^0_s} + (1+\frac{1}{1-\alpha})(m^2_\pi - m^2_K)$
$B_s \to K^+K^-$	$M^2_{B^0_s} + (3-\alpha+\frac{1}{1-\alpha})(m^2_\pi - m^2_K)$

The kinematics term (BCKG)

$$\mathcal{L}_{bckg}^{kin} = pdf_{bckg}^{kin}(M_{\pi\pi}, \alpha) = P'(\alpha) \cdot \frac{1}{Norm} \cdot \left(e^{(c_0 + M_{\pi\pi} \cdot c_1)} + c_2\right)$$

Pdf of the α variable.
Extract from separated fit on data

Mass shape of the background. Parameters c_i floating in the fit



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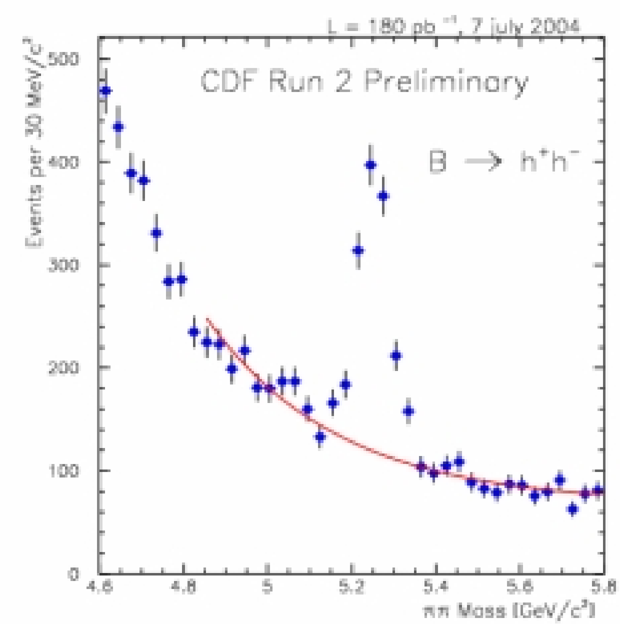


dE/dx Likelihood (signal)

σ* is the RMS of the Gaussian, it depends on the event and on the mass hypothesis

PID is the mean of the Gaussian:

$PID_K = 1$, $PID_\pi = 0$

For $B_{d,s} \to \gamma\,\delta$

$$\mathcal{L}_j^{PID} = pdf_{\gamma\delta}^{PID}(\mathrm{ID}(1),\ \mathrm{ID}(2), \sigma_\gamma^*(1), \sigma_\delta^*(2)\ ;\ PID_\gamma(1),\ PID_\delta(2)) =$$

$$= \frac{1}{\sigma_\gamma^*(1)\sqrt{2\pi}} \cdot e^{-\frac{1}{2}\left(\frac{\mathrm{ID}(1)-PID_\gamma(1)}{\sigma_\gamma^*(1)}\right)^2} \times \frac{1}{\sigma_\delta^*(2)\sqrt{2\pi}} \cdot e^{-\frac{1}{2}\left(\frac{\mathrm{ID}(2)-PID_\delta(2)}{\sigma_\delta^*(2)}\right)^2}$$

dE/dx Likelihood (background)

Assume the background made of pions and kaons only, the BCKG Likelihood is

$$\mathcal{L}_{bckg}^{PID} = pdf^{PID}(\mathrm{ID}(1),\, \mathrm{ID}(2), \sigma^*(1), \sigma^*(2)\ ;\ PID(1),\ PID(2)) =$$

$$= \left[f_\pi \cdot \frac{1}{\sigma_\pi^*(1)\sqrt{2\pi}} \cdot e^{-\frac{1}{2}\left(\frac{\mathrm{ID}(1)-PID_\pi(1)}{\sigma_\pi^*(1)}\right)^2} + (1-f_\pi) \cdot \frac{1}{\sigma_K^*(1)\sqrt{2\pi}} \cdot e^{-\frac{1}{2}\left(\frac{\mathrm{ID}(1)-PID_K(1)}{\sigma_K^*(1)}\right)^2} \right]$$

$$\times \left[f_\pi \cdot \frac{1}{\sigma_\pi^*(2)\sqrt{2\pi}} \cdot e^{-\frac{1}{2}\left(\frac{\mathrm{ID}(2)-PID_\pi(2)}{\sigma_\pi^*(2)}\right)^2} + (1-f_\pi) \cdot \frac{1}{\sigma_K^*(2)\sqrt{2\pi}} \cdot e^{-\frac{1}{2}\left(\frac{\mathrm{ID}(2)-PID_K(2)}{\sigma_K^*(2)}\right)^2} \right]$$

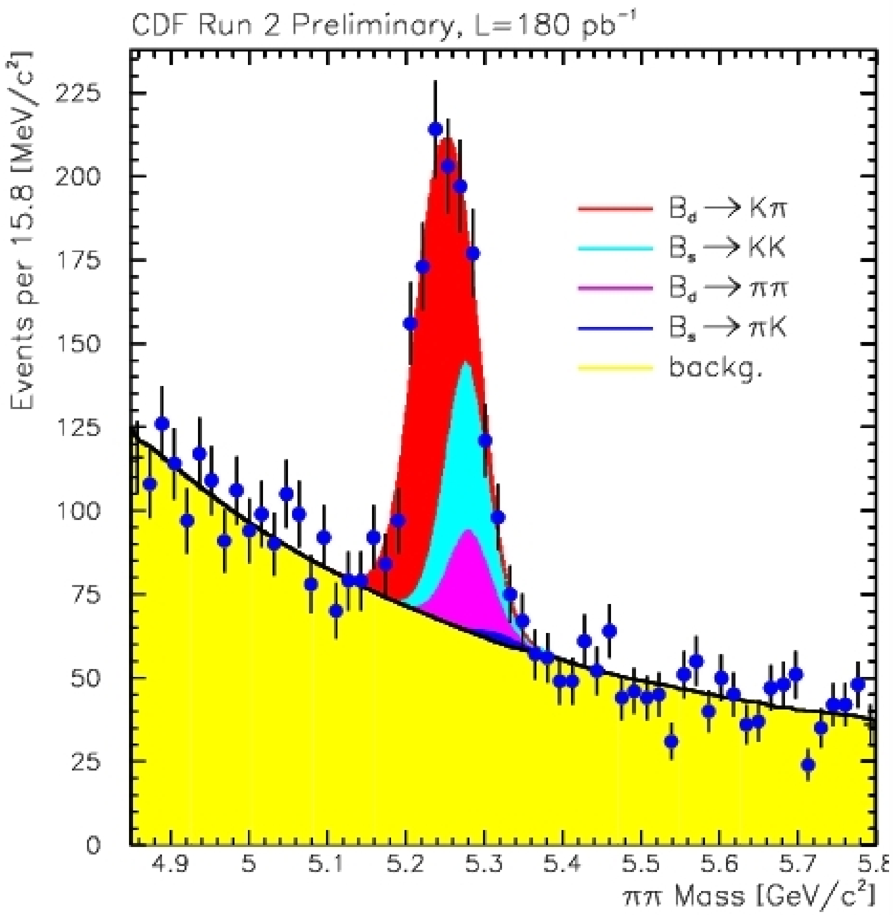
$f\pi$ is the pion fraction in background

Floating in the fit

Correlations between dE/dx measurements of two tracks in the same event (a.k.a. common-mode fluctuations) potentially bias the result of the fit.

The likelihood takes in to account this effect (although the formulas are considerably complicated and are not displayed here)

Fit Results



parameter	value
$f(B_d \to \pi\pi)$	0.15±0.03
$f(B_d \to K^\pm\pi^\mp)$	0.57±0.03
$A_{CP}(B_d \to K^\pm\pi^\mp)$	-0.05±0.08
$f(B_s \to K^\pm\pi^\mp)$	0.02±0.03
$f(B_s \to KK)$	0.26±0.03

Decay	# B
$B_d \to K^+\pi^-$	509
$B_d \to \pi^+\pi^-$	134
$B_s \to K^+K^-$	232
$B_s \to K^-\pi^+$	---

Biggest sample of Bs decays!

$B_d \to K^+\pi^-$ 509/180 pb^{-1}

(compare Babar 1600/220 fb^{-1})

Extraction of A_{CP}

The RAW fit results need to becorrected for relative acceptance, trigger and selection efficiency:

$$A_{CP} = \frac{N(\overline{B}^0_d \to K^-\pi^+) - N(B^0_d \to K^+\pi^-)}{N(\overline{B}^0_d \to K^-\pi^+) + N(B^0_d \to K^+\pi^-)}$$

$$A_{CP} = \frac{N(\overline{B}^0_d \to K^-\pi^+)_{RAW} \cdot \frac{\epsilon_{kin}(B^0_d \to K^+\pi^-)}{\epsilon_{kin}(\overline{B}^0_d \to K^-\pi^+)} - N(B^0_d \to K^+\pi^-)_{RAW}}{N(\overline{B}^0_d \to K^-\pi^+)_{RAW} \cdot \frac{\epsilon_{kin}(B^0_d \to K^+\pi^-)}{\epsilon_{kin}(\overline{B}^0_d \to K^-\pi^+)} + N(B^0_d \to K^+\pi^-)_{RAW}}$$

from Monte Carlo derive the ratio of efficiency for K+ and K- due to the different nuclear interaction rate for K^+ and K^- with detector material (1% correction)

$B_d \to \pi\pi / B_d \to K\pi$ Branching Ratio Ratio

The RAW fit results need to be corrected for relative acceptance, trigger and selection efficiency:

$$\frac{BR(B_d \to \pi\pi)}{BR(B_d \to K\pi)} = \left[\frac{N(B_d \to \pi\pi)}{N(B_d \to K\pi)}\right]_{RAW} \cdot \frac{\epsilon_{kin}(B_d \to K\pi)}{\epsilon_{kin}(B_d \to \pi\pi)} \cdot \frac{c_{XFT}(B_d \to K\pi)}{c_{XFT}(B_d \to \pi\pi)}$$

Get from Monte Carlo simulations the ratio of efficiencies from Kinematics and Kaon vs pion decays in flight and interaction probability.

Correct for specific ionization dependence of trigger efficiency in the level1 trigger (XFT). Use data from unbiased legs in $D^+ \to K^-\pi^+\pi^+$ control sample to derive correction.

Bs→KK/Bd→Kπ Branching Ratio Ratio

The RAW fit results need to becorrected for relative acceptance, trigger and selection efficiency:

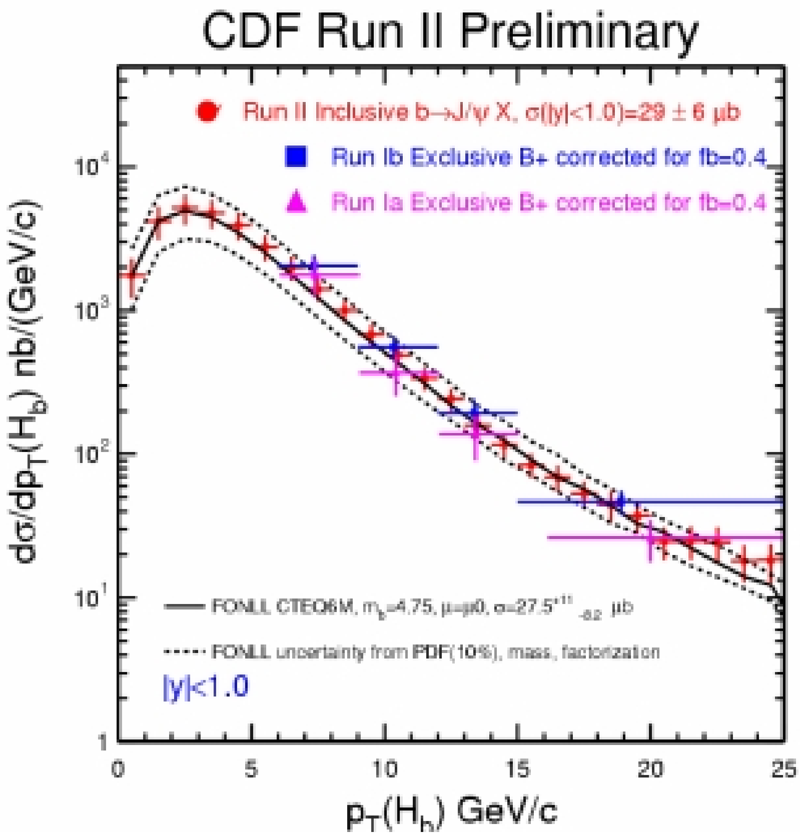
$$\frac{f_s \cdot BR(B_s \to KK)}{f_d \cdot BR(B_d \to K\pi)} = \left[\frac{N(B_s \to KK)}{N(B_d \to K\pi)}\right]_{RAW} \cdot \frac{\epsilon_{kin}(B_d \to K\pi)}{\epsilon_{kin}(B_s \to KK)} \cdot \frac{c_{XFT}(B_d \to K\pi)}{c_{XFT}(B_s \to KK)} \cdot \frac{\epsilon_{iso}(B_d)}{\epsilon_{iso}(B_s)}$$

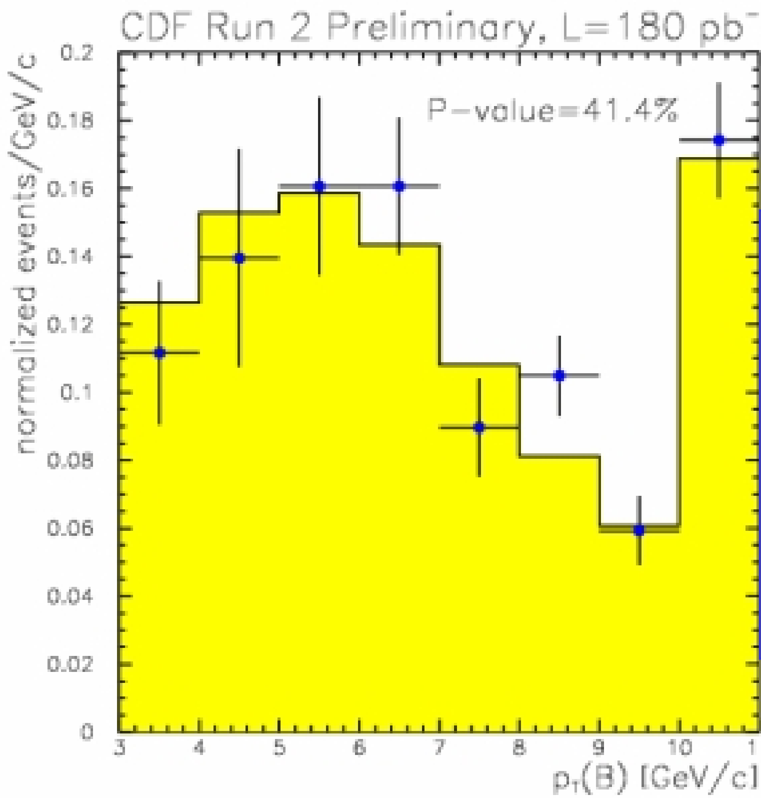
At colliders we can only measure the product of production fractions time BR. fs(d) is the probability that a b quark hadronize in a Bs(d) meson. Averages exists in the PDG (dominated by LEP measurements and b time integrated mixing). Interest in an indpendent CDF measurement!

Fragmentation process might be different for

Bs and Bd meson. Derive the efficiency of the Isolation cut from samples of fully reconstructed Bs/Bd mesons

Production Pt spectra





Overflow bin!

B→ hh trigger accept very soft B → big samples available!

Measurement of the production Pt spectrum from inclusive b→JψX in this region important for reliable MC simulation

Efficiency corrections (3)

Correction factor	Kin. and Trigger	B-Isolation
$\frac{\epsilon(B_d \to K\pi)}{\epsilon(B_d \to \pi\pi)}$	0.93 ± 0.01	-
$\frac{\epsilon(B_d \to K\pi)}{\epsilon(B_s \to KK)}$	1.13 ± 0.01	0.935 ± 0.10
$\frac{\epsilon(B_s \to KK)}{\epsilon(B_d \to \pi\pi)}$	0.82 ± 0.01	1.07 ± 0.11
$\frac{\epsilon(B_d^0 \to K^+\pi^-)}{\epsilon(\overline{B}_d^0 \to K^-\pi^+)}$	1.018 ± 0.001	-

Results

- Annihilation dominated modes
- For Bs→ππ assume same time evolution as for the Bs→KK (see next)

$$\frac{BR(B_d \to \pi\pi)}{BR(B_d \to K\pi)} = 0.24 \pm 0.06\ (stat.) \pm 0.05\ (syst.)$$

$$A_{\mathrm{CP}} = -0.04 \pm 0.08\ (stat.) \pm 0.01\ (syst.)$$

$$\frac{f_d \cdot BR(B_d \to \pi^\pm\pi^\mp)}{f_s \cdot BR(B_s \to K^\pm K^\mp)} = 0.48 \pm 0.12\ (stat.) \pm 0.07\ (syst.)$$

$$\frac{f_s \cdot BR(B_s \to K^\pm K^\mp)}{f_d \cdot BR(B_d \to K^\pm\pi^\mp)} = 0.50 \pm 0.08\ (stat.) \pm 0.07\ (syst.)$$

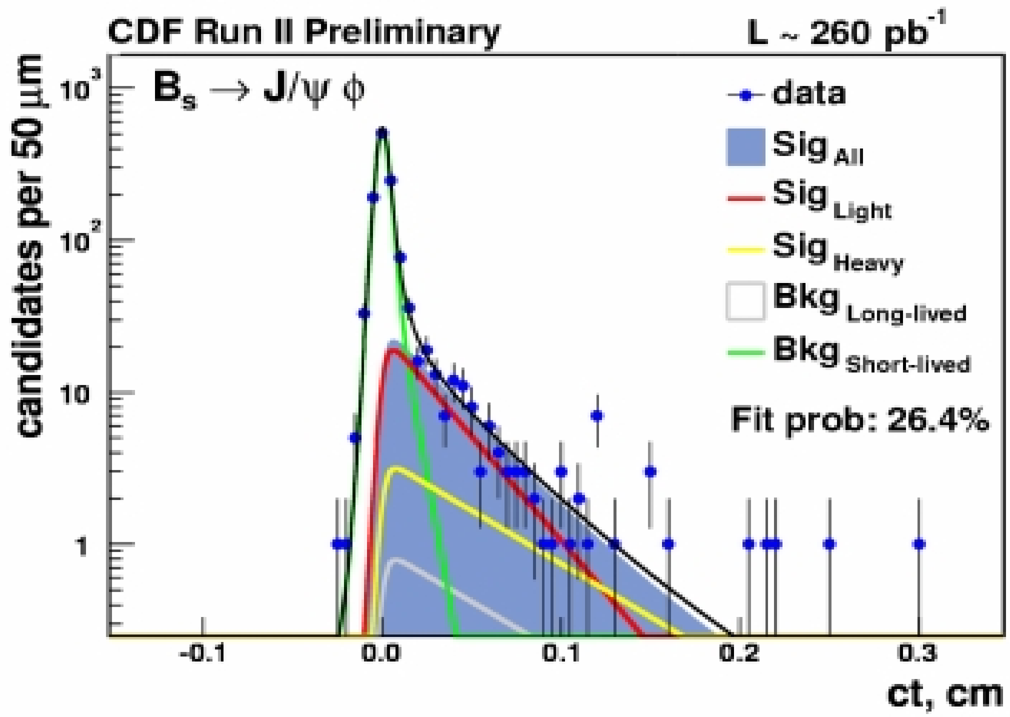
$$\frac{BR(B_s \to \pi^\pm\pi^\mp)}{BR(B_s \to K^\pm K^\mp)} < 0.10\ @\ 90\%\ C.L.$$

$$\frac{f_s \cdot BR(B_s \to K^\pm\pi^\mp)}{f_d \cdot BR(B_d \to K^\mp\pi^\pm)} < 0.11\ @\ 90\%\ C.L.$$

$$\frac{BR(B_d \to K^\pm K^\mp)}{BR(B_d \to K^\mp\pi^\pm)} < 0.17\ @\ 90\%\ C.L.$$

Sensitivity to a sizeable ΔΓs

$$A_0 = 0.784 \pm 0.039 \pm 0.007$$
$$A_{||} = (0.510 \pm 0.082 \pm 0.013)e^{(1.94 \pm 0.36 \pm 0}$$
$$|A_\perp| = 0.354 \pm 0.098 \pm 0.003$$
$$\tau_L = 1.05\ ^{+0.16}_{-0.13} \pm 0.02 \text{ ps}$$
$$\tau_H = 2.07\ ^{+0.58}_{-0.46} \pm 0.03 \text{ ps}$$
$$\Delta\Gamma/\Gamma = 0.65\ ^{+0.25}_{-0.33} \pm 0.01$$
$$\Delta\Gamma = 0.47\ ^{+0.19}_{-0.24} \pm 0.01 \text{ ps}^{-1}$$



-CDF recently measured an anomalously large (even if not yet statistically compelling) value of the lifetime difference in the Bs system

-Use angular analysis to project out CP-odd and CP-even component of Bs→J/ψφ

What's the implication on the two body decays measurement ?

Sensitivity to a sizeable $\Delta\Gamma s$

$$\frac{f_s \cdot BR(B_s \to K^{\pm} K^{\mp})}{f_d \cdot BR(B_d \to K^{\pm} \pi^{\mp})} = 0.50 \pm 0.08 \pm 0.09$$

$dN(B_s \rightarrow KK)/dt \propto R_L \exp(-t_L) + R_H \exp(-t_H)$

-The above central value assumes:

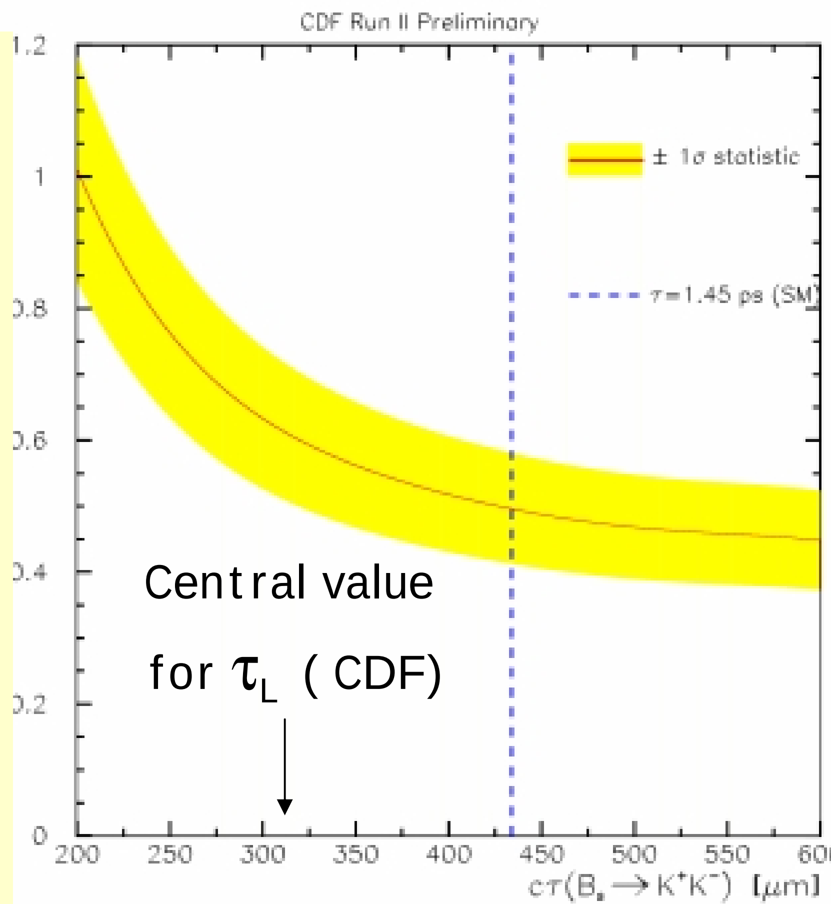
-R_H=0 (no Heavy Bs decay to KK or, equivalently, no tree contribution)

- $\tau_L = 1/(\Gamma_s + \Delta\Gamma_s/2) = 1.45$ ps

(from SM $\Delta\Gamma_s/\Gamma_s = 0.12 \pm 0.06$

and $\Gamma s = \Gamma d$)

Yellow band shows acceptance corrected BR for any assumed effective $B_s \rightarrow KK$ lifetime on the X axis



Summary of systematics

source	$\frac{f_s}{f_d} \cdot \frac{BR(B_s \to KK)}{BR(B_d \to K\pi)}$	$A_{\mathrm{CP}}(B_d \to K\pi)$	$\frac{BR(B_d \to \pi\pi)}{BR(B_d \to K\pi)}$	$\frac{f_d}{f_s} \cdot \frac{BR(B_d \to \pi\pi)}{BR(B_s \to KK)}$
mass resolution	$^{+0.001}_{-0.004}$	$^{+0.001}_{-0.001}$	$^{+0.001}_{-0.002}$	$^{+0.001}_{-0.001}$
dE/dx **correlation: RMS(s)**	$^{+0.043}_{-0.031}$	$^{+0.002}_{-0.002}$	$^{+0.034}_{-0.025}$	$^{+0.029}_{-0.017}$
dE/dx **correlation:** pdf**(s)**	$^{+0.002}_{-0.002}$	$^{+0.002}_{-0.002}$	$^{+0.000}_{-0.000}$	$^{+0.002}_{-0.002}$
dE/dx **tail**	$^{+0.056}_{-0.056}$	$^{+0.003}_{-0.003}$	$^{+0.020}_{-0.020}$	$^{+0.017}_{-0.017}$
dE/dx **shift**	$^{+0.001}_{-0.002}$	$^{+0.001}_{-0.001}$	$^{+0.001}_{-0.003}$	$^{+0.017}_{-0.005}$
input masses	$^{+0.027}_{-0.028}$	$^{+0.003}_{-0.003}$	$^{+0.009}_{-0.010}$	$^{+0.009}_{-0.010}$
background model	$^{+0.005}_{-0.005}$	$^{+0.002}_{-0.002}$	$^{+0.003}_{-0.003}$	$^{+0.000}_{-0.000}$
lifetime	$^{+0.004}_{-0.004}$	-	-	$^{+0.004}_{-0.004}$
isolation efficiency	$^{+0.051}_{-0.051}$	-	-	$^{+0.050}_{-0.050}$
MC statistics	$^{+0.004}_{-0.004}$	$^{+0.001}_{-0.001}(*)$	$^{+0.003}_{-0.003}$	$^{+0.006}_{-0.006}$
charge asymmetry	-	$^{+0.002}_{-0.002}$	-	-
XFT-bias correction	$^{+0.010}_{-0.007}$	-	$^{+0.004}_{-0.004}$	$^{+0.015}_{-0.010}$
$p_T(B)$ **spectrum**	$^{+0.007}_{-0.007}$	-	-	$^{+0.007}_{-0.007}$
$\Delta\Gamma_s/\Gamma_s$ **Standard Model**	$^{+0.007}_{-0.006}$	-	-	$^{+0.006}_{-0.006}$
TOTAL	**±0.09**	**±0.01**	**±0.04**	**±0.07**

Systematics (1)

a) Mass resolution: the mass resolution is input from MC. It is rescaled to match the D^0 resolution on data.

b) dE/dx - uncertainty on RMS(s): repeat the fit varying the correlation RMS from its minimum (0.24) to its maximum (0.52), quote the differences wrt to central fit.

c) dE/dx - uncertainty on the shape p(s): repeat the fit at central value of RMS(s) = 0.38 assuming a Double Dirac delta for p(s) shape quote the difference wrt to central fit.

d) dE/dx – tails: the central fit assumes Gaussian dEdx pdf. Repeat the fit with more accurate parameterization of the pdf; repeat the fit adding extra component.

Systematics (2)

e) input masses: the fit is done on data in which the recipe used for mass measurement at CDF II was applied. Input masses in the kinematics pdf are those measured by CDF II. Repeat the fit varying $M(B_d)$ and $M(B_s)$ within their statistical uncertainties (0.92 and 1.29 MeV/c^2). Quote the differences wrt the central fit.

f) Background model: the fit assumes mass spectrum of bckg = exp + C. Repeat the fit with p_2,p_3,p_4 and quote the difference wrt central value.

g) B lifetimes: relative kinematics efficiencies depend on the lifetime assumed in MC. Re-evaluate efficiencies after simultaneous shift of B_s lifetime (+1σ) and B_d (-1σ) and viceversa. σ is the PDG2004 uncertainty. Quote difference wrt central value.

Systematics (3)

h) Isolation efficiency: has a ~ 10% from measurement on data. Reevaluate the efficiency at +/- 1σ and quote difference wrt central value

i) MC statistics: kinematics efficiencies have statistical error. Reevaluate them at +/- 1σ and quote difference wrt the central fit.

l) Trigger dE/dx correction: the correction function have uncertainties. Stretch (push) K/π discrepancy shifting simultaneously the correction coefficients by 1σ, reevaluate the correction, and quote differences wrt the central fit

Systematics (4)

m) $\Delta\Gamma_s/\Gamma_s$ (Standard Model)

$\Delta\Gamma_s/\Gamma_s$: Standard Model predicts ~ 0.12±0.06 and

$B_s \rightarrow K^+K^-$ to be dominated by the short-lived component.

We derive the systematic uncertainties from these assumptions by varying $\Delta\Gamma_s/\Gamma_s$ from 0.06 to 0.18 , re-evaluating the relative efficiencies and quoting the differences wrt the central fit.

Experimental Comparison

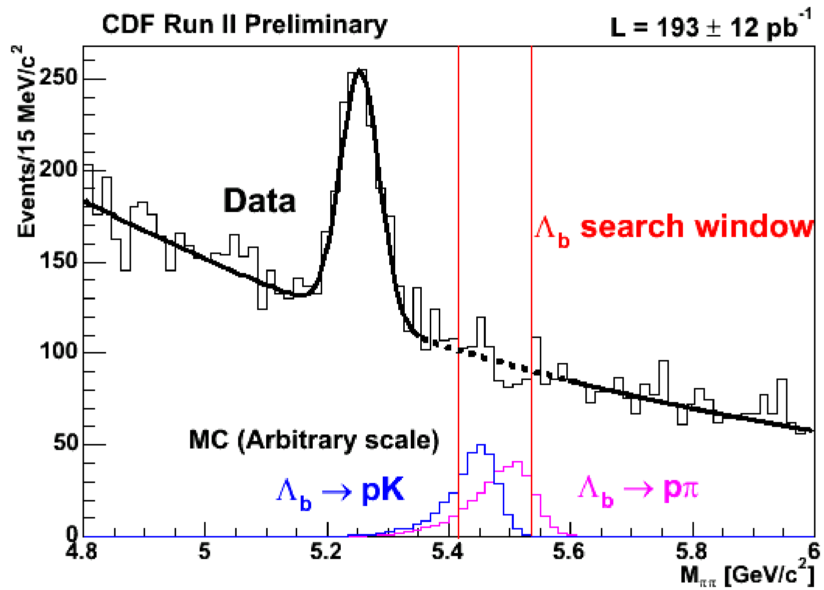
	CDF	Babar	Belle
$N(B_d \to K^+\pi^-)$	509/180 pb^{-1}	1600/200 fb^{-1}	1030/140 fb^{-1}
A_{CP} $(B_d \to K^+\pi^-)$	-0.04±0.08±0.01	-0.133±0.030±0.009	-0.085±0.030±0.013
$BR(\pi\pi)/BR(K\pi)$	0.24±0.08	0.25± 0.04	0.24 ± 0.04

- A_{CP} measurement with systematic uncertainty comparable to Babar/Belle
  - Expect to reach comparable stat. precision with 0.8 fb^{-1} of data (2005?)
- Ratio of B_d Branching Ratio consistent with world average and provide valuable cross-check for the other Branching ratio measurements

What's behind the corner?

Where are the Λ_b?

- Used the same data to look for evidence of Λ_b's
  - Large direct CP asymmetries expected
- Theory predicts:
  - BR($\Lambda_b \to pK$), BR($\Lambda_b \to p\pi$) ~ 10^{-6} -$2*10^{-6}$ (Mohanta, Phys. Rev. D63:074001, 2001)
- Current limits:
  - BR($\Lambda_b \to pK$) <$50*10^{-6}$, BR($\Lambda_b \to p\pi$) <$50*10^{-6}$ @90% C.L.
- Blind optimization to reduce background in the Λ_b mass region including the contribution from B0→hh'
- Normalize to BR(B_d^0->Kπ)
  - Extract number of BR(B_d^0->Kπ) events from a fit like the one described before.



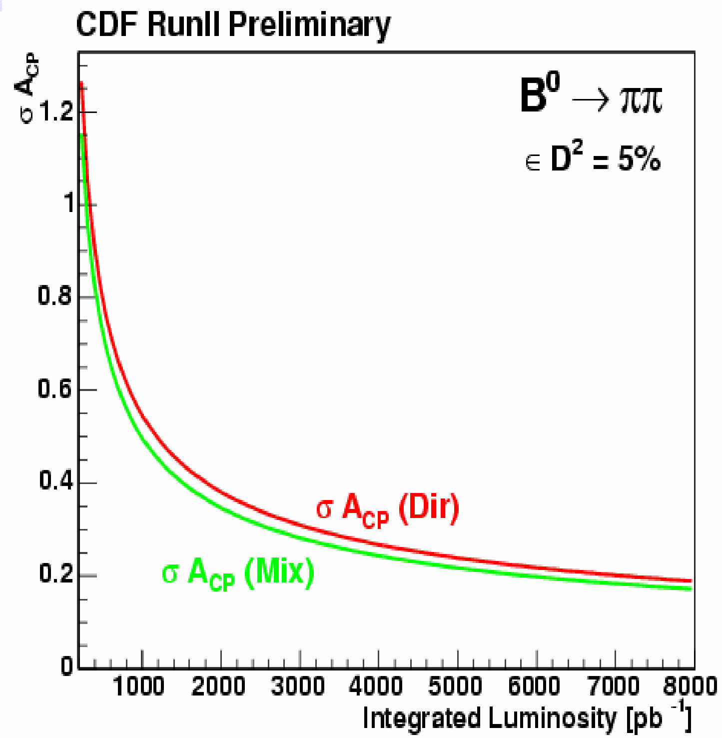
Use BR($B_d^0 \to K\pi$)=(17.4±1.5) 10^{-5} and f_Λ/f_d=0.25±0.04 Obtain :

BR($\Lambda_b \to p\pi$)+ BR($\Lambda_b \to pK$) < 22 *10^{-6}

Improved sensitivity in the future with combined TOF and dE/dx PID proton identification

Perspective for futher measurements

- CDF has twice the luminosity on tape wrt to this analysis, better tracking alignment and reconstruction make mass and vertex resolution even better:
  - Bs-->Kπ should be observable
    - Direct CP asymmetry
  - Bs→KK lifetime will be measured soon and will give interesting information on $\Delta\Gamma s/\Gamma s$
    - Interesting resolution even with current statistics if $\Delta\Gamma s$ so large
    - If $\Delta\Gamma s$ different from what is observed in $J/\psi\ \phi$ → new physics
- Direct CP asymmetry will be competitive with current B-Factory with twice the data we have on tape by now
- Time dependent CP violation measurement interesting further down the road due to the low flavor tagging efficiency at hadron machines (needs full nominal Run II luminosity)
  - standalone and clean measurment of CKM angle γ is the ultimate goal



- Need to keep the trigger working fine even at high instantaneous luminosity
  - Relentless day-to-day fight to save bandwidth!
  - Important trigger/daq upgrades in the pipeline

Conclusion

New exciting result from CDF:

$$A_{CP} = -0.04 \pm 0.08\ (stat.) \pm 0.01\ (syst.)$$

$$\frac{f_d \cdot BR(B_d \to \pi^{\pm}\pi^{\mp})}{f_s \cdot BR(B_s \to K^{\pm}K^{\mp})} = 0.48 \pm 0.12\ (stat.) \pm 0.07\ (syst.)$$

$$\frac{f_s \cdot BR(B_s \to K^{\pm}K^{\mp})}{f_d \cdot BR(B_d \to K^{\pm}\pi^{\mp})} = 0.50 \pm 0.08\ (stat.) \pm 0.07\ (syst.)$$

- No evidence (yet) for the $B_s \to K\pi$ decay
- No large annhilation in $B_s \to \pi\pi$
- Other charmless mode have been measured or searched for with available data, expect many new results with increasing data size and improved offline quality. Stay tuned…

Summary of CDF result for HFAG

B_d Charmless Hadronic CP Asymmetries

$$A_{CP}(B_d \to K^+\pi^-) = -0.04 \pm 0.08 \pm 0.006$$

$$A_{CP}(B^- \to \phi K^-) = \frac{\Gamma(B^- \to \phi K^-) - \Gamma(B^+ \to \phi K^+)}{\Gamma(B^- \to \phi K^-) + \Gamma(B^+ \to \phi K^+)} = -0.07 \pm 0.17(stat)^{+0.06}_{-0.05}(syst)$$

B^+ Charmless Hadronic Branching Fractions

$$\mathcal{B}(B^+ \to \phi K^+) = (7.2 \pm 1.3(stat) \pm 0.7(syst)) \times 10^{-6}$$

B_d Charmless Hadronic Branching Fractions

$$\frac{\mathcal{B}(B_d \to \pi^+\pi^-)}{\mathcal{B}(B_d \to K^+\pi^-)} = 0.24 \pm 0.06 \pm 0.04$$

$$\frac{\mathcal{B}(B_d \to K^+K^-)}{\mathcal{B}(B_d \to K^+\pi^-)} < 0.17 \text{ at } 90\% \text{ CL}$$

B_s Charmless Hadronic Branching Fractions

$$\frac{f_s\mathcal{B}(B_s \to K^+K^-)}{f_d\mathcal{B}(B_d \to K^+\pi^-)} = 0.50 \pm 0.08 \pm 0.09$$

$$\frac{f_s\mathcal{B}(B_s \to K^+\pi^-)}{f_d\mathcal{B}(B_d \to K^+\pi^-)} < 0.11 \text{ at } 90\% \text{ CL}$$

$$\frac{\mathcal{B}(B_s \to \pi^+\pi^-)}{\mathcal{B}(B_s \to K^+K^-)} < 0.10 \text{ at } 90\% \text{ CL}$$

The above results assume equivalent lifetime distributions for the B_s and B_d deca

$$\mathcal{B}(B_s \to \phi\phi) = (1.4 \pm 0.6(\text{stat}) \pm 0.2(\text{syst}) \pm 0.5(\text{BR's})) \times 10^{-5}$$

Relies indirectly on f_s/f_d through the normalization mode $B_s \to J/\psi\phi$.

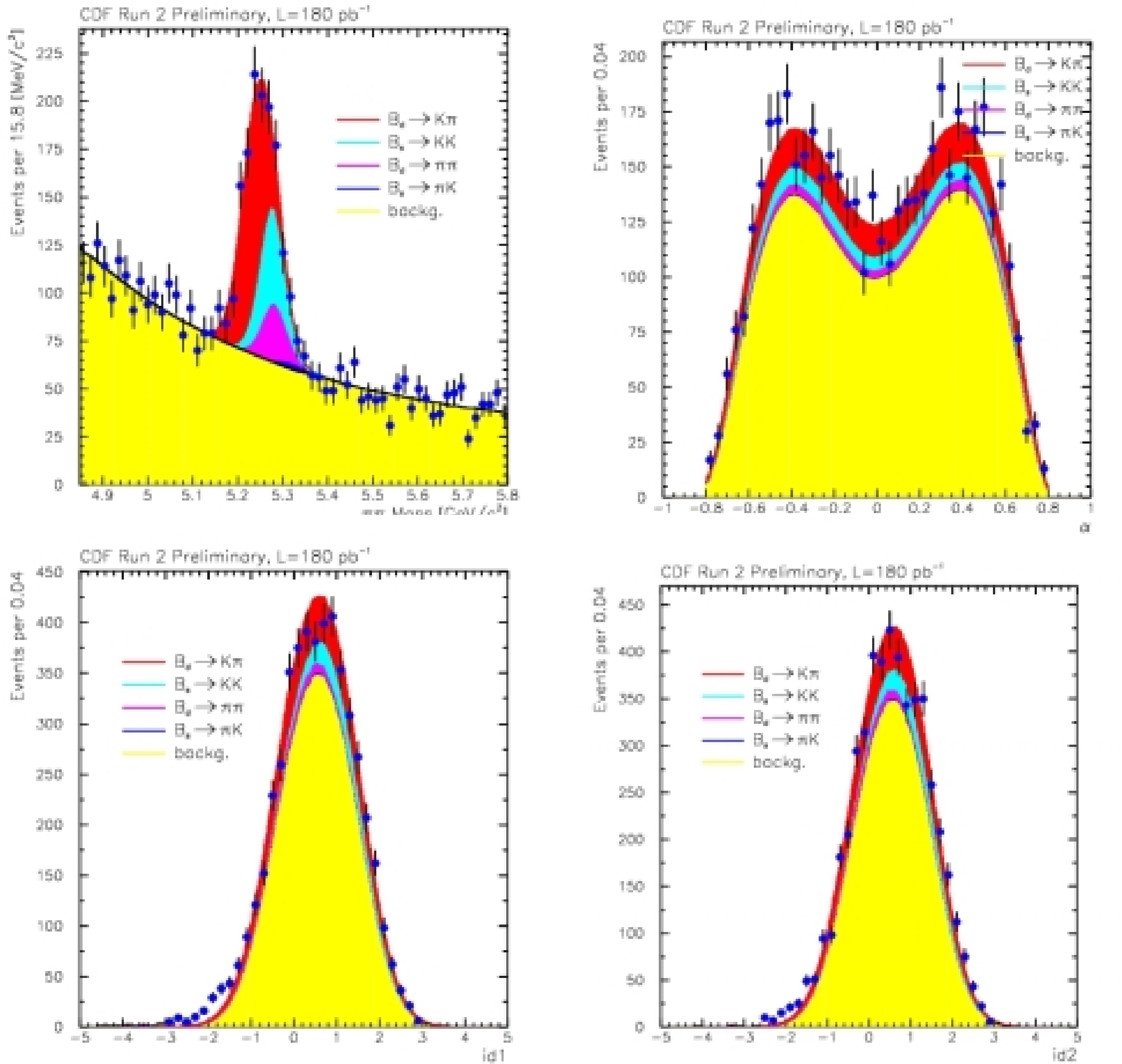
Λ_b Charmless Hadronic Branching Fractions

$$\mathcal{B}(\Lambda_b \to p\pi + pK) < 22 \times 10^{-6} \text{ at } 90\% \text{ CL}$$

Assumes on $f_\Lambda/f_b = 0.25 \pm 0.04$ and $\mathcal{B}(B_d \to K^+\pi^-) = (1.74 \pm 0.15) \times 10^{-5}$.

…for new CDF result also on Heavy Flavour Averaging Group pages

Backup Slides


CDF Run 2 Preliminary, L=180 pb⁻¹
Events per 15.8 [MeV/c²]
ππ Mass [GeV/c²]
Events per 0.04
α
id1
id2
Bd → Kπ
Bs → KK
Bd → ππ
Bs → πK
backg.

Raw fit results

parameter	value
$f(B_d \to \pi\pi)$	0.15±0.03
$f(B_d \to K^{\pm}\pi^{\mp})$	0.57±0.03
$A_{\mathrm{CP}}(B_d \to K^{\pm}\pi^{\mp})$	-0.05±0.08
$f(B_s \to K^{\pm}\pi^{\mp})$	0.02±0.03
$f(B_s \to KK)$	0.26±0.03
$\frac{N(B_s \to KK)}{N(B_d \to K\pi)}$	0.47±0.08
$\frac{N(B_d \to \pi\pi)}{N(B_d \to K\pi)}$	0.26±0.06
$\frac{N(B_d \to \pi\pi)}{N(B_s \to KK)}$	0.55±0.14
$f_\pi \ (4.85 < M_{\pi\pi} < 5.125)$	0.53±0.01
$f_\pi \ (5.125 < M_{\pi\pi} < 5.4)$	0.45±0.02
$f_\pi \ (5.4 < M_{\pi\pi} < 5.8)$	0.46±0.02
background fraction	0.82±0.01
signal fraction	0.18±0.01
c_0	14.0±6.2
c_1	-2.1±0.4
c_2	8.7±57.5

Pion fraction in BCKG

BCKG shape

dE/dx in the Likelihood

dE/dx information is included through the ID variable:

$$\mathrm{ID}(track) = \frac{\frac{dE}{dx}_{meas}(track) - \frac{dE}{dx}_{exp-\pi}(track)}{\frac{dE}{dx}_{exp-K}(track) - \frac{dE}{dx}_{exp-\pi}(track)}$$

ID can be written as a function of the dE/dx pulls

$$pull_{\pi}(track) = \frac{\frac{dE}{dx}_{meas}(track) - \frac{dE}{dx}_{exp-\pi}(track)}{\sigma_{dE/dx}(track)}$$

$$pull_{K}(track) = \frac{\frac{dE}{dx}_{meas}(track) - \frac{dE}{dx}_{exp-K}(track)}{\sigma_{dE/dx}(track)}$$

dE/dx in the Likelihood (cont'd)

Write pull = pull (ID, σ*)

$$pull_\pi(track) = \mathsf{ID}(\mathsf{track}) \cdot \frac{\frac{dE}{dx}_{exp-K}(track) - \frac{dE}{dx}_{exp-\pi}(track)}{\sigma_{dE/dx}(track)} = \frac{\mathsf{ID}(\mathsf{track})}{\sigma^*(track)}$$

$$pull_K(track) = (\mathsf{ID}(track) - 1) \cdot \frac{\frac{dE}{dx}_{exp-K}(track) - \frac{dE}{dx}_{exp-\pi}(track)}{\sigma_{dE/dx}(track)} = \frac{\mathsf{ID}(\mathsf{track}) - 1}{\sigma^*(track)}$$

We assume the pull distribution to be Gaussian. Actually pdf(pull) has a small tail at high values, consider this effect in the systematics. Therefore the pdf(ID) becomes Gaussian with:

Mean: 0 for pions and 1 for kaons

RMS: σ* → depends on the mass hypothesis and changes event by event

Final results

$$\frac{BR(B_d \to \pi\pi)}{BR(B_d \to K\pi)} = 0.24 \pm 0.06\ (stat.) \pm 0.05\ (syst.)$$

[LP03: 0.26 ± 0.11 ± 0.055]

$$A_{\mathsf{CP}} = -0.04 \pm 0.08\ (stat.) \pm 0.01\ (syst.)$$

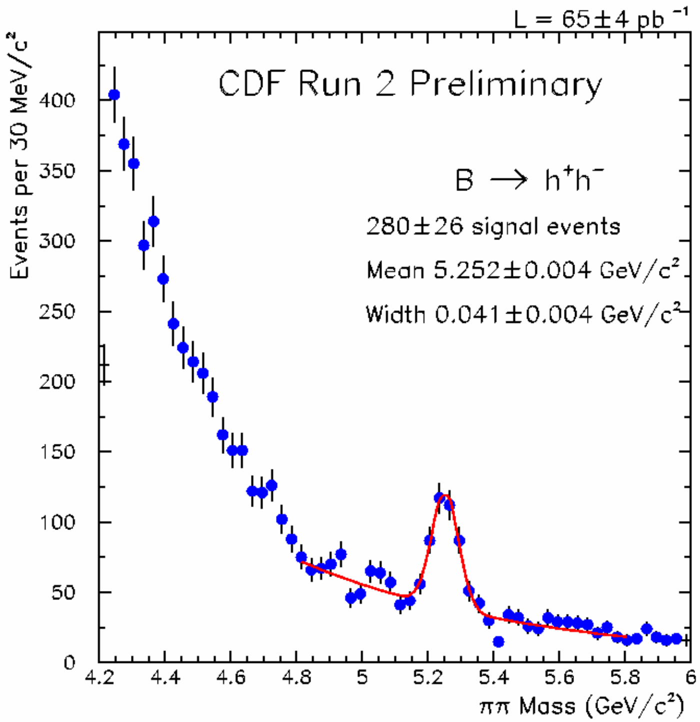
[LP03: 0.02 ± 0.15 ± 0.017]

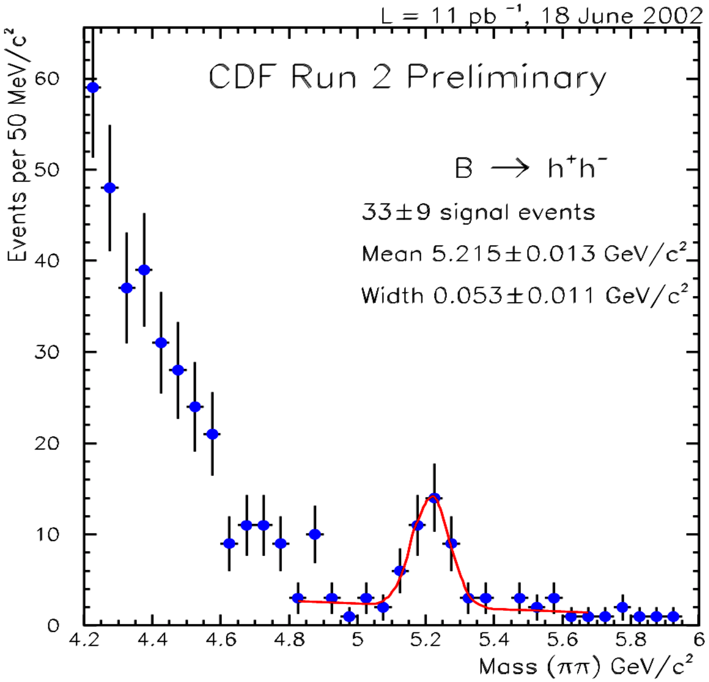
$$\frac{f_d \cdot BR(B_d \to \pi^{\pm}\pi^{\mp})}{f_s \cdot BR(B_s \to K^{\pm}K^{\mp})} = 0.48 \pm 0.12\ (stat.) \pm 0.07\ (syst.)$$

$$\frac{f_s \cdot BR(B_s \to K^{\pm}K^{\mp})}{f_d \cdot BR(B_d \to K^{\pm}\pi^{\mp})} = 0.50 \pm 0.08\ (stat.) \pm 0.07\ (syst.)$$

[LP03: 0.74 ± 0.2 ± 0.22]

Disentangling the B→h+h- contributions (I)

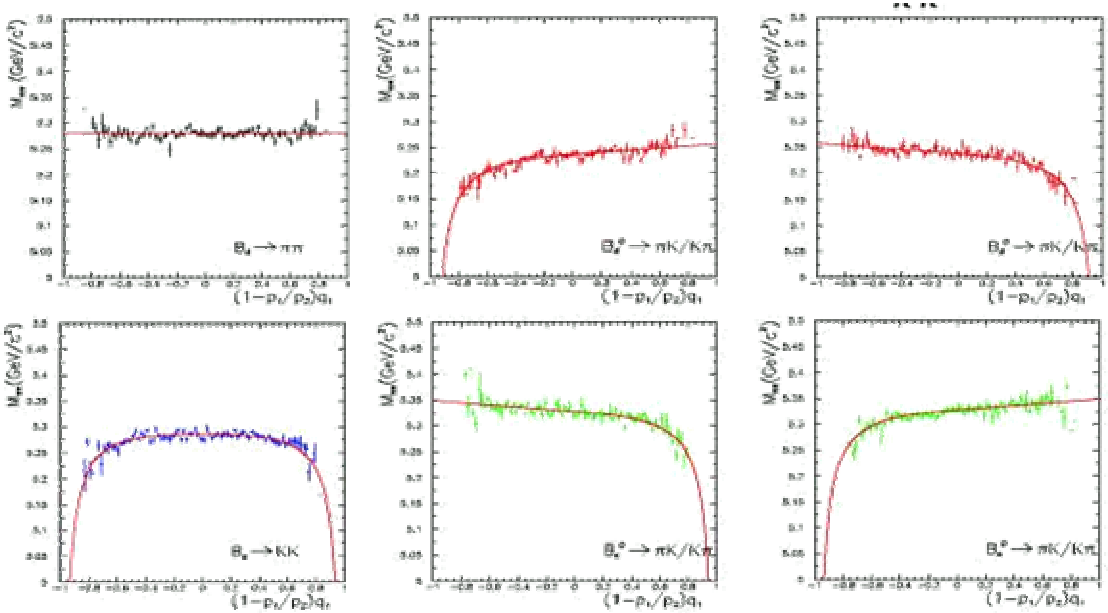




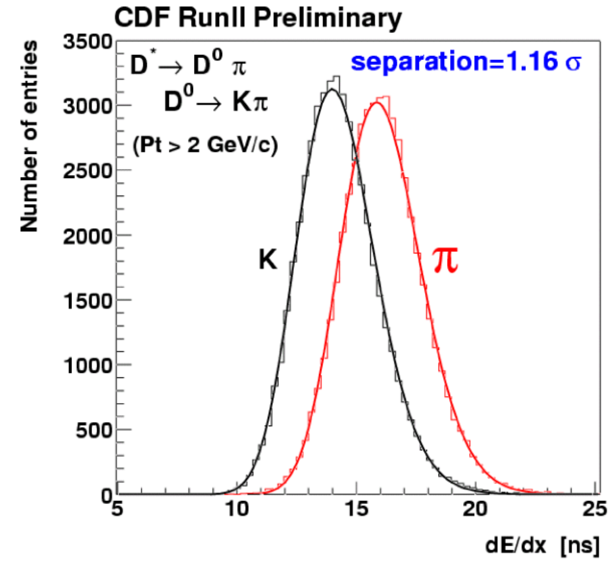
Must disentangle contributions from each mode
To do this we use:
-Kinematical variable separation $M_{\pi\pi}$ vs $\alpha=(1-p_1/p_2)\cdot q_1$
-dE/dx based K and π identification

Disentangling the $B \to h^+h^-$ contributions (II)

$M_{\pi\pi}$ vs a for each $B \to h^+h^-$ mode



dE/dx calibration using $D^{*\pm} \to D^0\pi^\pm$, $D^0 \to K^\pm\pi^\pm$ (π from D* unambiguously distinguishes K, π from D^0)



Sanity check: Measure Ratio of Branching Ratios

CDF : $\Gamma(B_d \to \pi^+\pi^-)/\Gamma(B_d \to K^+\pi^-) = 0.26 \pm 0.11 \pm 0.055$, PDG: $0.29^{+0.13}_{-0.12}{}^{+0.01}_{-0.02}$

Yield for each mode:

- $B_d \to \pi^+\pi^-$ 148±17
- $B_d \to K^\pm \pi^\pm$ 39±14
- $B_s \to K^\pm \pi^\pm$ 3±11
- $B_s \to K^+K^-$ 90±17(stat) ±17(stat)
  First observation !

Method works ! Confirmed by Sanity check against ratio of branching ratios

Have first observation of $B_s \to K^+K^-$

Its a CP Eigenstate: Can use this To measure $\Delta\Gamma_s$ as well !!

Where are the Λ_b (syst.)?

- Largest source of syst is the uncertainty on the Pt spectra, and the production fraction.
- However, the impact on the limit is small.
- Limit most sensitive to background uncertainty.

$B \to h^{\pm}h^{\mp}$	
Shape of the background	5.7%
Background	
Shape of the background	3.3%
Relative Λ_b/B Efficiency	
$\Lambda_b \to p\pi/\Lambda_b \to pK$ ratio	2.3%
Window position	1.2%
Window width	9%
Lifetime	3.6%
L1 trigger efficiency for protons	6%
$p_T(\Lambda_b)$	17%
Overall systematic	21%
$BR(B_d \to K\pi)$	8.6%
f_{Λ_b}/f_B	16%

'ABLE I: Summary of the systematic errors.